Acta Agrobotanica

DOI: 10.5586/aa.1790

Publication history
Received: 2018-11-19
Accepted: 2019-10-12
Published: 2019-12-31

Handling editor
Piotr Sugier, Faculty of Biology and Biotechnology, Maria Curie-Skłodowska University in Lublin, Poland

Authors' contributions
EN: leading the project, manuscript writing and editing; TP: field work, manuscript editing, data processing; AV: mathematical processing of data, graphic work; AP: sampling and data analysis; NP: data processing, manuscript editing

Funding
This project was supported by a grant from the Russian Foundation for Basic Research (RFBR) and the Government of Arkhangelsk region No. 17-44-290111. The work by NP was also conducted within the framework of the state task 0409-2015-0141 of the N. Laverov Federal Center for Integrated Arctic Research.

Competing interests
No competing interests have been declared.

Citation
Nakvasina E, Parinova T, Volkov A, Popova A, Prozherina N. Soil modification in a chronosequence of postagricultural ecosystems of the intrazonal lithogenic matrix (Arkhangelsk region, Russia). Acta Agrobot. 2019;72(4):1790. https://doi.org/10.5586/aa.1790

ORIGINAL RESEARCH PAPER

Soil modification in a chronosequence of postagricultural ecosystems of the intrazonal lithogenic matrix (Arkhangelsk region, Russia)

Elena Nakvasina[1]*, Tatyana Parinova[1], Alexey Volkov[1], Anna Popova[2], Nadezhda Prozherina[3]

[1] Higher School of Natural Sciences and Technologies, Northern (Arctic) Federal University named after M. V. Lomonosov, Russian Federation
[2] Agrochemical Service Station "Arkhangelskaya", Russian Federation
[3] Laboratory of Population Ecology, N. Laverov Federal Center for Integrated Arctic Research, Russian Federation

* Corresponding author. Email: e.nakvasina@narfu.ru

Abstract

Processes of soil self-restoration and soil modification in the chronosequence of postagricultural ecosystems located within the intrazonal (floodplain) soils of boreal forests were studied. Successional changes in ecological features of the floodplain meadow soil properties in the postagricultural period were considered. We used arable land plots (22 model fields) in the Northern Dvina River delta (Primorsky District, Arkhangelsk region, Northwestern Russia) that have been removed from agricultural practice for the past 50 years and are currently at the self-overgrowing stage. Primary/secondary floodplain meadows with natural floodplain soils were used as reference plots. Changes in soil profiles and chemical properties in an old-arable horizon were observed during the restoration of abandoned fields. Floodplain soils of the Northern Dvina River basin occupied 4.8% of the area. These soils were characterized by high fertility and were actively used in agricultural production in the past. Postagricultural ecosystems of the Northern Dvina River floodplain tended to form natural waterlogged soils to varying extents. Ecosystems were characterized by a short period of soil restoration. The soil restoration process was slower than the vegetation cover restoration process. Soil fertility of the arable horizon persisted for 20 years. A cost-effective return of floodplain meadow lands to agricultural production is feasible over a period of 40 years. Then, soils return to natural floodplain soils, whereby they become waterlogged and lose their fertility.

Keywords

floodplain; meadow; postagricultural ecosystem; abandoned fields; dynamics; restoration

Introduction

Currently, human-induced landscape modifications are critical. For the region of Russia near Northern Europe, landscape modification has been related to pioneering since the eleventh century with the use of slash-and-burn and forest-field agriculture [1]. In the taiga (boreal forests) zone, fallow land plots have been extensively identified [2] and are used to predict the properties of modern postagricultural ecosystems [3,4]. Their area is from 45 to 70 million ha in Russia, according to different sources [5,6]. From the mid-twentieth century, there has been a global tendency for the loss of agricultural lands [7–9]. Agrogenic soils in the boreal zones have been affected more adversely by changes in social and economic life in Russia during the 1990s than in other Russian regions. Approximately 200,000 ha of agricultural lands were abandoned over the last 25 years in the Arkhangelsk region [10]. In some administrative districts of the Arkhangelsk region, over 90% of agricultural lands have been abandoned [11].

Approaches to examine self-regenerating succession in Russia are similar to those in other countries, including monitoring soil and vegetation coverage properties with studies at different development stages. In Russia, land abandonment is spontaneous. However, in other European countries, there are regular stationary observations of abandoned land for the maintenance of biological diversity and other purposes [12,13]. Abandoned hayfields and pastures are studied more than abandoned arable lands in boreal zones [6]. Additionally, demutation processes are more pronounced in abandoned arable lands because of the plough-layer changes not only in the soil profile but also in the soil cover of the entire landscape [14]. Problems such as community recovery rates under different conditions and interactions of demutation succession of vegetation and soil properties have not yet been resolved [2,3,14]. However, the process of soil formation may be critical for the restoration of postagricultural vegetation to original conditions [15].

The study of vegetation chronosequences in fallow lands on different lithogenic matrices of soil formation would enable the development of management procedures for demutation and land rehabilitation. The self-organization of ecosystems and rebalancing of their components at every stage of progressive succession take place under self-regeneration in the postagricultural period. These processes involve both biocenosis (vegetation, animals) and the abiotic parts (soils) of ecosystems. Actually, the restoration of lands takes place after their use in agricultural production, and a problem arises regarding these management processes and their predictive power under different climatic, forest vegetation, and soil/hydrological conditions [14]. To solve this problem, the recovery rate of soil/vegetation coverage in postagricultural succession, changes in vegetation and soil morphological characteristics and properties at different stages of self-regeneration, the effects of agricultural technologies and their duration, and the effects of ambient biocenosis must be studied. Research on fallow lands of the boreal belt in Russia is seldom conducted, and data on the successional processes in these lands are rare.

The objective of this study was to determine the soil self-regeneration processes and soil modification occurring in postagricultural ecosystems in a time-series (chronosequences) of fallow lands within the intrazonal (floodplain) soils of the boreal forests (the Arkhangelsk region). Postagricultural ecosystems within the intrazonal lithogenic matrix in the Northern Dvina River delta (farming lands abandoned at different times) were the objects of this study.

Material and methods

Arable land plots (model fields) abandoned during the last 50 years were selected in the Northern Dvina River delta (Primorsky District, Arkhangelsk region, Russia, 64°57–58′ N, 40°26–30′ E) in years 2014–2016. The climate in the region is subarctic marine. The period with temperatures above 10°C lasts 70–85 days and the cumulative amount of heat for this period is 1,100–1,300°C. The average temperature of the warmest month (July) is 16°C. The air is humid during all seasons and air humidity reaches 80%. The frost-free period lasts 105 days. Snow cover forms in November and a cold winter lasts 175 days with the lowest temperature of −48°C. The average temperature in the coldest month (January) is −12°C. Snow cover is consistent with an average depth of 45 cm. Annual precipitation is 500–530 mm. The average annual temperature is +0.4°C. The growing season is 135 continuous days. The self-regenerating plots were located within the intrazonal (floodplain) soil area (Fig. 1). Primary/secondary floodplain meadows with natural floodplain soils were used as reference plots. All plots were located in the central part of the island floodplain of the river delta.

Fallow lands of different ages were selected based on land-use plans in correlation with chemical maps developed in the 1980s (“Arkhangelskaya” Agrochemical Station). For each land plot, the chemical soil properties during the period of intensive land use were analyzed.

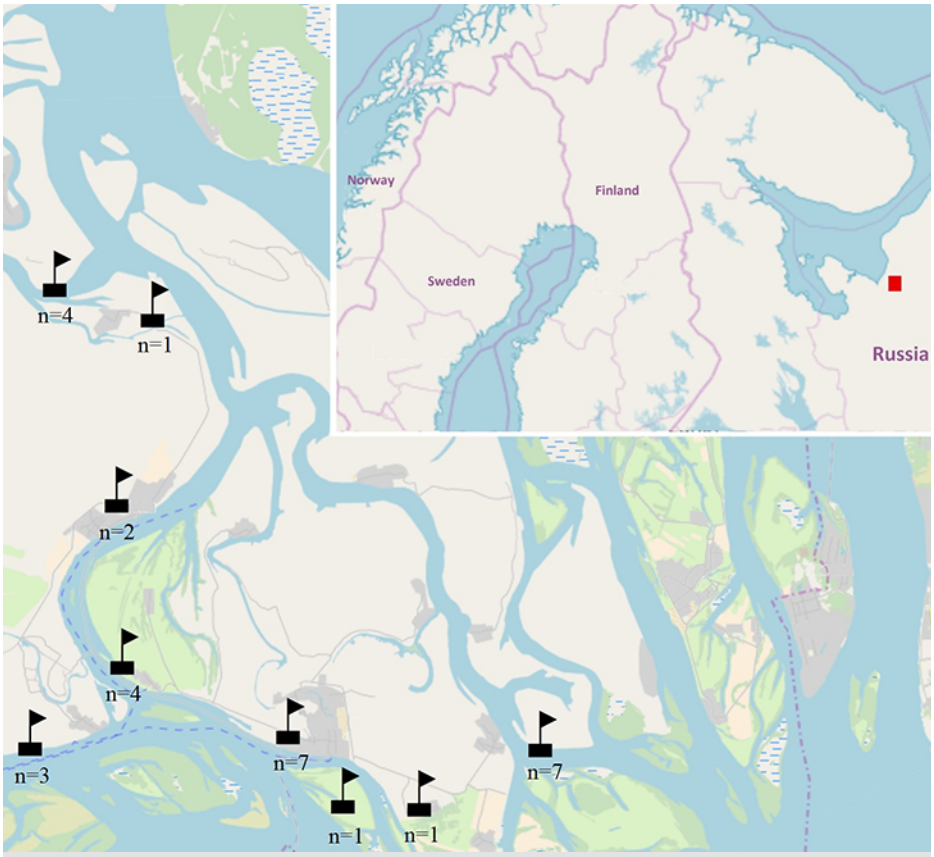

Fig. 1 Test plot locations (flagged) and amount in the Northern Dvina River delta.

Complete geobotanic descriptions were implemented within uniform vegetation cover of each field in test plots with areas of 100 m^2 [16,17]. Names of vascular plants in Latin are given according to Czerepanov [18]. Within each test plot, the soil profile was classified according to the Russian classification system [19] and also according to the World Reference Base for Soil Resources (WRB) [20].

Soil samples were taken using a steel soil-sampler from the middle of the arable horizon at 10 excavation points. Soil moisture and bulk density were determined using the thermogravimetric method, particle density was determined using the pycnometer method, and total soil porosity and aeration porosity were calculated [21,22].

Total porosity was calculated as: $\varphi = (1 - D_b/D_d) \times 100$, where φ – total porosity (%); D_b – bulk density (g cm^{-3}); D_d – particle density (g cm^{-3}). Aeration porosity (percentage of pores with air) was calculated as: $\varphi_a = \varphi - M \times D_b$, where φ_a – aeration porosity (%); M – soil moisture (%).

Salt-replaceable acidity (pHKCl), hydrolytic soil acidity (H^+) by the Kappen method, and total exchangeable bases were measured. Soil organic matter (SOM) was determined using the Tyurin method and the mobile phosphorus and potassium compounds were detected using the Kirsanov method. The cation exchange capacity (CEC) and base cations (%) were calculated.

All studied plots were grouped by age of fallow formation: 5 years (five fields), 6–19 years (four fields), 20–40 years (10 fields), over 50 years (three fields), and eight natural plots. All data were statistically analyzed (mean ± standard error of mean) by group.

A permutation test [23,24] was used. This is a type of statistical significance test in which the distribution of the test statistic under the null hypothesis is obtained by calculating all possible values of the test statistic under rearrangements of the labels for the observed data points. Fraker and Peacor [25] concluded that permutation tests provide an advantage over ANOVAs in their ability to test a wider range of models. Statistical significance was accepted at the level of $p < 0.05$.

Results

The studied fallow passed through regeneration stages including the classical stages: tall grass (wild grass), creeping stem grass (long-rooting), bunch grass (loose shrub), and tussock grass (thick sod). Initially, in the first year, an abandoned field was overgrown by annual weed plants (species including *Stellaria*, *Sonchus arvensis* L., *Chenopodium album* L., and *Atriplex patula* L.), as well as taproots and root-sucker perennials [including *Cirsium arvense* (L.) Scop. and *Mentha arvensis* L.]. In the beginning of the first year of abandonment, large and aggressive species, such as *Cirsium arvense*, *Heracleum sibiricum* L., and *Heracleum sosnowskyi* Manden, having high seed productivity and substantial allopathic effects invaded the abandoned fields from neighboring meadows. These species crowded out annuals and also prevented the dispersal of new species for a long period. In such a state, a grass stand could prevail for several decades and at 20 years following field abandonment, the stand could be covered by leguminous species, mixed herbs, and gramineous species. Later, especially during network amelioration or disturbance, in the absence of hay production, fallow lands were overgrown by small-leaved forests, primarily dominated by willow species that were represented by *Salix triandra* L., *Salix pentandra* L., *Salix caprea* L., *Salix acutifolia* Willd., and *Salix viminalis* L. with an admixture of *Padus avium* Mill., *Sorbus aucuparia* L., and *Alnus incana* (L.) Moench, as well as the occasional *Alnus glutinosa* (L.) Gaertn.

The herbaceous coverage during succession affected soil properties. Significant differences in SOM, acidity (pHKCl), P_2O_5, H^+, bulk density, and porosity were revealed using permutation tests (Tab. 1). At the beginning of fallow formation, the physical properties of soils (Tab. 2) were the most unstable. Soil bulk density decreased by 10% for 5 years. In the following years, soil density was dependent upon field use and cultivated plants. On average, it corresponded to natural (nonploughed) lands (p = 0.98–0.99), except for fallow lands after 40 years. Critical changes in total porosity and aeration porosity of the plough-layer were not observed. That was provided by the ploughing layer (which resulted from heavy land use) and by the numerous roots of the developing herbaceous cover. In fallow land after 50 years, the total porosity was similar to that of natural soils; however, the proportion of pores filled with air was 1.5 times higher than that of natural soils.

Overall, soils of 50-year fallow lands significantly differed from those of younger fallow lands and natural soils ($p < 0.01$) in their physical properties. These results occurred because of the growth of small-leaved deciduous species and soil waterlogging.

The SOM content up to 40 years following fallow soil abandonment did not significantly differ with that of natural soils. Low-SOM content in younger fallow lands was related to soil agricultural degradation, which resulted from the degree of soil ploughing and the decrease in amelioration in the region within the last 30 years. After 6 years, SOM content increased to 3.1% and corresponded to that of natural soils. Sod formed in the herbaceous cover and the number of perennials increased; perennials provided sufficient leaf fall to enrich the soil when haymaking was lacking. After 20 years of abandonment, the SOM content in old-arable soils increased to 2.8%, which was close to the level in the natural soils (p = 0.78–0.99). In old fallow land (over 50 years of natural regeneration) organic matter accumulated. This was related to soil bogging by groundwater (floodplain water dam) and was also related to a reduction in the leaching of nutrients.

After 20 years, pHKCl varied from 5.8 to 5.9 and was at a level close to that of natural soils. With further fallow formation (over a period of 40 years) acidity increased more actively with waterlogging, and the soil became medium acidic (pHKCl = 4.7).

Mobile phosphorus and potassium content changed in different ways. A high level of phosphates (47.1–50.3 mg 100 g^{-1}) resulting from fertilizer distribution during the period of agricultural use persisted in fallow lands for 40 years and was 3 times higher than that of P_2O_5 content in soils in natural meadows (Tab. 3). The low acidity of floodplain soils and the hardness of the Northern Dvina River water caused phosphorus accumulation. If the self-regeneration period was longer, phosphorus removal took place and the phosphorus content was similar to that in natural soils (p = 0.99). However, the mobile phosphorus content in old-arable soils was still rather high (19.6 mg 100 g^{-1}), but was lower than the average value (26.7 mg 100 g^{-1}) for the surrounding area.

Tab. 1 Results of the permutation tests to determine the differences in soil properties in ecosystems of various duration following abandonment.

Properties	Sum of squares	Variance	Iteration	*p*
SOM (%)	136.5*; 27.4	34.1*; 1.0	5,000	**0.001**
Acidity (pHKCL)	3.6; 6.0	0.9; 0.2	5,000	**0.012**
P_2O_5 (mg 100 g^{-1})	7,006.9; 12,067.0	1,751.7; 482.7	5,000	**0.018**
K^2O (mg 100 g^{-1})	209.6; 1,244.0	52.4; 49.7	490	0.484
H^+ (mmol 100 g^{-1})	150.1; 34.4	37.5; 1.4	5,000	**0.001**
CEC (mmol 100 g^{-1})	269.8; 1,159.6	67.4; 46.4	1,055	0.168
Bulk density (g cm^{-3})	0.14; 0.02	0.03; 0.00	5,000	**0.001**
Total porosity (%)	1,051.8; 780.1	262.9; 31.2	5,000	**0.001**
Aeration porosity (%)	776.8; 2,860.7	194.2; 114.4	3,025	0.178

Note: * first value – between treatments; second value – within treatments; boldface – a significant difference.

Tab. 2 Dynamics of changes in the physical properties of fallow floodplain soils on postagricultural succession.

Abandoned period (years)	Bulk density (g cm^{-3})	Total porosity (%)	Aeration porosity (%)
5 (*n* = 5)	1.18 ±0.02; 1.14–1.25	51.24 ±0.75; 48.35–52.89	34.92 ±1.28; 31.55–39.67
6–19 (*n* = 4)	1.12 ±0.01; 1.10–1.15	55.63 ±0.38; 54.55–56.52	34.74 ±1.19; 30.89–37.03
20–40 (*n* = 10)	1.19 ±0.04; 1.00–1.33	54.67 ±1.56; 47.91–61.98	35.03 ±3.28; 18.71–57.71
50 (*n* = 3)	0.67 ±0.04; 0.61–0.76	73.20 ±1.50; 69.60–75.60	29.36 ±4.26; 18.98–35.46
Natural lands (*n* = 8)	1.17 ±0.07; 0.69–1.39	53.97 ±2.80; 45.06–72.51	23.29 ±4.93; 3.17–43.59

Before semicolon: mean and standard error of mean; after semicolon: minimum and maximum value of parameter.

Tab. 3 Dynamics of agrochemical properties of the arable horizon soils on postagricultural succession.

Abandoned period (years)	SOM (%)	Acidity (pHKCL)	P_2O_5 (mg 100 g^{-1})	K_2O (mg 100 g^{-1})
5 (*n* = 5)	1.84 ±0.18; 1.19–2.43	5.93 ±0.22; 5.32–6.54	47.14 ±2.27; 41.9–55.2	11.18 ±1.21; 8.3–15.8
6–19 (*n* = 4)	3.14 ±0.29; 2.40–4.01	5.83 ±0.08; 5.66–6.08	49.75 ±3.81; 42.7–62.6	18.13 ±4.27; 8.6–31.7
20–40 (*n* = 10)	2.77 ±0.29; 1.82–4.70	5.33 ±0.14; 4.56–6.03	50.26 ±9.20; 5.8–107.4	15.99 ±2.34; 8.0–30.5
50 (*n* = 3)	9.74 ±1.07; 8.17–12.35	4.69 ±0.07; 4.58–4.86	19.63 ±4.17; 13.7–29.8	10.60 ±1.02; 8.3–12.6
Natural lands (*n* = 8)	3.34 ±0.31; 2.13–5.37	5.56 ±0.21; 4.70–6.33	17.01 ±6.94; 3.0–65.0	12.14 ±2.37; 5.9–27.8

Before semicolon: mean and standard error of mean; after semicolon: minimum and maximum value of parameter.

The exchange of phosphorus and potassium content in fallow lands did not significantly differ with that of natural soils (11–18 mg 100 g^{-1}). In the first 5 years of fallow formation, K_2O content increased slightly. In soils of the 20-year fallow lands, the K_2O content increased by 1.5 times, up to 18.1 mg 100 g^{-1}, which could be caused by a large amount of grass-fall. Later, the mobile potassium content became stable.

Fallow formation and soil sorption parameters of floodplain arable lands (total exchangeable base amount, CEC, base saturation) were quite high (Tab. 4), which is typical of natural floodplain soils and agricultural lands of the region. Soil fertility decreased during the process of floodplain groundwater bogging over the long term. In this case, rapid soil acidification accompanied by the accumulation of hydrogen ions in soil sorption complex took place. H^+ reached 9.6 mmol 100 g^{-1}, which unfavorably

Tab. 4 Dynamics of soil absorption complex properties of a plough-layer in fallow floodplain soils on postagricultural succession.

Abandoned period (years)	H^+ (mmol 100 g^{-1})	Total exchangeable bases (mmol 100 g^{-1})	Cation-exchangeable capacity (mmol 100 g^{-1})	Base cations (%)
5 ($n = 5$)	1.39 ±0.20; 0.83–1.98	14.12 ±1.87; 9.2–20.8	15.51 ±1.70; 11.18–21.63	89.88 ±2.28; 82.29–96.16
6–19 ($n = 4$)	1.66 ±0.13; 1.28–1.98	18.68 ±1.15; 16.0–21.2	20.34 ±1.27; 17.28–23.18	91.86 ±0.26; 91.30–92.59
20–40 ($n = 10$)	3.01 ±0.36; 1.43–4.71	14.84 ±1.51; 9.51–22.2	17.86 ±1.49; 13.27–25.83	82.13 ±2.51; 71.67–93.95
50 ($n = 3$)	9.61 ±1.25; 7.28–12.5	22.53 ±4.31; 12.9–31.1	32.14 ±3.07; 25.40–38.38	68.04 ±7.34; 50.79–81.03
Natural lands ($n = 8$)	2.91 ±0.32; 1.55–4.01	20.25 ±3.20; 9.4–38.0	23.16 ±3.01; 13.19–40.01	84.94 ±2.81; 71.27–94.98

Before semicolon: mean and standard error of mean; after semicolon: minimum and maximum value of parameter.

affected vegetation development, in spite of the high content of humic substances and the high amount of exchange bases.

Discussion

The Northern Dvina is one of the largest rivers in Russia near Northern Europe. It is a typical lowland river with an average grade of 0.07‰ and combined recharge in which snow feed accounts for 50%, rain feed for 20%, and underground feed for 30% of annual flow. High spring floods, normal summer and fall water levels, and low winter water levels are typical. The spring floods last 1 to 3 weeks. The fall floods last 1.5–2 months on average [26,27]. The river mouth of the Northern Dvina (Fig. 1) is classified as a tidal estuary with a multibranched delta and river-mouth strand. In the river delta, dry land consists of 55% of the area. The central part of the floodplain is the widest area and it contains the main islands and near-shore part of the Northern Dvina. It is characterized by high water and a high groundwater table (1–2 m depth). Silt deposits with a high content of fine sandy/silty particles are typical [28: p. 29–53]. Additionally, the floodplain of the Northern Dvina has a meandering river, combined effects of continental (zonal) conditions, erosion and accumulation, and floodplain and alluvial processes. These processes take place in the formation of segmental ridge floodplains and are destroyed by anthropogenic transformation [29].

Floodplain (alluvial) soils of the Northern Dvina River basin occupy 4.8% of the regional area; 1.3% of which are bogged [30] and 10.3% are occupied by ploughed lands [10]. These soils are characterized by high fertility and primarily they have been cultivated by farmers. They have always been extensively used in the agricultural production of the region.

The majority of the natural meadows of the Northern Dvina River delta is intermediate between primary and secondary meadows because of the duality of the exo- and endodynamic nature of their formation. They originate with a primary phase of vegetation formation (mesophytic grasses, shrubs, and trees) primarily on sand bars. This stage is maintained by human activities, such as regular grazing or hay making. The reduction in economic activity results in a transformation in the secondary floodplain meadows. This stage is also maintained by regular rational hay making or grazing [29]. Similar processes have been described by other researchers [13].

Meadow soils in the Northern Dvina River delta are typical Fluvisols, grey humic (soddy). Scanty alluvial stratified soils with gleying of different extent in the lower part of the soil profile also occur. Soils are uniform brownish and mixed and have a properly structured plough-layer form after meadow ploughing. The large-scale agricultural effects on plough lands within the floodplain significantly improves soil quality. This surpasses the average quality that is established in the Arkhangelsk region and in the agroclimatological zone where the fields under studied are located [10].

During postagrogenesis, changes in the environmental, floristic, production, and structural features of floodplain biocenosis take place. All types of cyclic dynamics and succession variability, both those of vegetation and soil, are observed in the fallow lands.

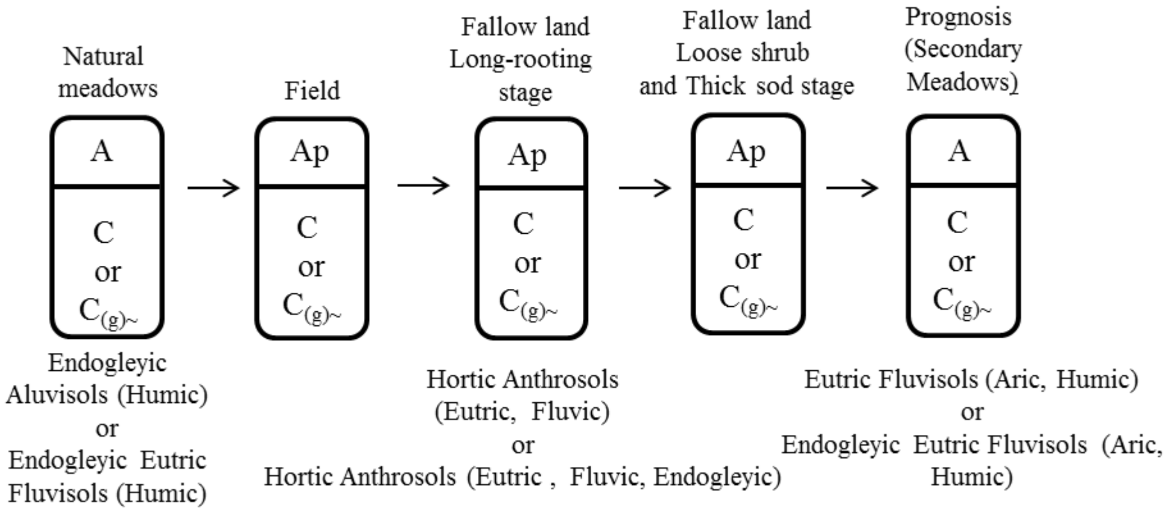

Fig. 2 Modifications of postagricultural alluvial soil formation in the Northern Dvina River delta floodplain.

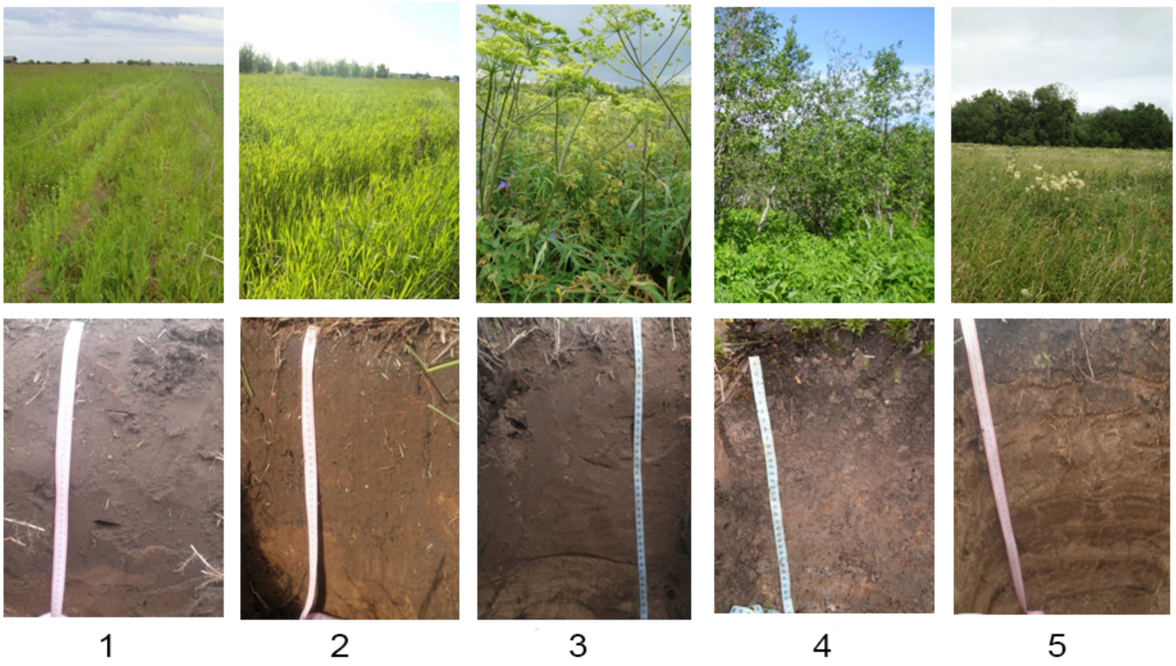

Fig. 3 Vegetation and typical profiles of alluvial soils in the Northern Dvina delta floodplain in fallow lands of different ages: at 5 years (1), 6–19 years (2), 20–40 years (3), over 50 years (4), and in natural lands (5).

Soils pass through certain evolutionary stages during the period of fallow self-regeneration and phytocoenotic successional changes are evident in meadows. Changes occur in both soil morphological and chemical properties. Morphogenetic changes in the fallow soil chronosequence pass through two main stages: regradation (regraded subtype) and postargogenesis (postagrogenic subtype). This makes it possible to predict and to estimate the evolutionary rate of self-regeneration (Fig. 2). Furthermore, morphological characteristics of the arable horizon (smooth lower boundary, clumpy structure, and brown color) are observed in all chronosequence soils (Fig. 3).

On the long creeping stem (long-rooting) stage of phytocenosis in the upper part of the arable layer, a young humic soil layer (W) appears and a sod layer starts to form. This layer is considered to be a feature of the regraded soil subtype. Features of the arable soil layer persist in all regraded soils: cloggy structure, dark color, and a well-distinguished even lower boundary. The sod-humic layer forms within 20 years of arable land self-regeneration at the bunch (loose shrub) and tussock (thick sod) stages of phytocenosis development. This layer is considered the main diagnostic feature of postagricultural soil succession [31]. Typical postagricultural alluvial sod soil forms, having traces of past ploughing (uniformly colored layer and a well-distinguished even lower boundary of the former plough-layer). Later, soils attain features of natural soils, and the distinct boundary of the plough-layer begins to diffuse. A layer forms that is already a sod layer but there still is an arable layer matrix [32]. Alluvial soils of fallow lands continue to be structured for a long period of time, and after at least 20 years of the fallow land formation of the soil, it is still cloggy and close to that of arable lands in structure. In the arable layer of alluvial soils, the loss of agrogenic features is observed after 40 years of abandonment, soils become similar to natural soils, as estimated by morphological characteristics.

The morphological evolution of soils is accompanied by changes in agrogenic features. However, it is predicted that fallow soils develop toward their natural state. In lithological matrices of zonal soils, postagricultural successions develop into ecosystems of zonal types [33]. This relationship is broken in intrazonal soils, especially as the formation of the future vegetation community depends on the first years of successional development. The higher soil fertility of former agricultural systems in the floodplain can, in different ways (positive or negative), affect vegetation development (restoration), which defines the structure of the vegetation community [34,35].

Postagricultural ecosystems of the Northern Dvina River floodplain tend to form natural soils that are water bogged to different extents. The restoration period is shorter then in zonal and extrazonal soils, where this process lasts for periods greater than 200 years [36]. The regeneration of natural floodplain soils can be expected within 100 years. It is likely caused by floodplain processes and damage to network amelioration developed during the period of intensive land use during agricultural production. Soil restoration is delayed by vegetation cover restoration. Soil fertility persists in the arable layer matrix for 20 years. Cost-effective floodplain soils returning to agricultural production are possible within a period of 40 years. The period of restoration for northern floodplain soils is similar to that for black earth soil, and the recommended time period for the return to agricultural production is no longer than 40–50 years [32]. These terms agree with the regeneration model for fallow ecosystems wherein the carbon content re-establishes itself within 40 years of long-term overgrowth of fallow land [36].

The restoration of fallow land and the problem of recultivation have two main aspects. On the one hand, with the restoration of fallow land, the rehabilitation of natural biomes takes place [37]. It is essential to predict landscape formation, both with respect to biological diversity and landscape aesthetics [13]. On the other hand, the reestablishment of soil fertility takes place (in other words, letting the soil rest). This is critically important for agricultural production in this modern period of world land degradation [38].

Within the territory of Russia, it is required to return 30–35% (8–10 million ha) of fallow lands to active agricultural use [39]. Soil quality and the proximity of land plots to cities are the most important criteria for the selection of land for return to active agricultural use [40].

Conclusion

The maintenance of soil properties in floodplain fallow ecosystems (fertility of arable lands during the course of their use in agricultural production) persists for 20 years. During this period, arable land rehabilitation does not impose substantial costs. In 40 years of abandonment, soils take on the properties that are similar to those of natural floodplain soils. Hence, this is a time limit for the economic return of fallow lands to ploughed lands. With long-term fallow formation (over 40 years), conditions of a disturbed amelioration network, shrub invasion, and water bogging take place. As a result, simultaneous humus content and hydrolytic acidity increase, whereas deterioration of physical properties and base saturation decrease. It is impractical to return such fallow lands to croplands.

References

1. Тишков [Tishkov] АА [AA]. Биогеография антропоцена Северной Евразии [Biogeografija antropocena Severnoj Evrazii]. Известия РАН, Серия географическая [Izvestija RAN, Serija geograficheskaja]. 2015;6:7–23.
2. Бобровский [Bobrovskij] МВ [MV]. Лесные почвы Европейской России: биотические и антропогенные факторы формирования [Lesnye pochvy Evropejskoj Rossii: bioticheskie i antropogennye faktory formirovanija]. Москва [Moskva]: Товарищество научных изданий [Tovarishhestvo nauchnyh izdanij]; 2010.
3. Сорокина [Sorokina] ОА [OA], Рыбакова [Rybakova] АН [AN]. Почвенно-экологический подход при оценке возможности использования залежей в различных стадиях сукцессий [Pochvenno-jekologicheskij podhod pri ocenke vozmozhnosti ispol'zovanija zalezhej v razlichnyh stadijah sukcessij]. Вестник КрасГАУ [Vestnik KrasGAU]. 2012;5:134–140.
4. Наквасина [Nakvasina] ЕН [EN], Голубева [Golubeva] ЛВ [LV]. Идентификация постагрогенных лесов в национальном парке "Кенозерский" [Identifikacija postagrogennyh lesov v nacional'nom parke "Kenozerskij"]. Вестник Северного (Арктического) федерального университета, Серия "Естественные науки" [Vestnik Severnogo (Arkticheskogo) federal'nogo universiteta, Serija "Estestvennye nauki"]. 2015;4:75–82. https://doi.org/10.17238/issn2227-6572.2015.4.75
5. Свинцов [Svincov] ИП [IP], Кулик [Kulik] КН [KN], Чмыр [Chmyr] АФ [AF]. Леса на землях, выбывших из сельскохозяйственного оборота АПК России [Lesa na zemljah, vybyvshih iz sel'skohozjajstvennogo oborota APK Rossii]. In: Агроэкологическое состояние и перспективы использования земель России, выбывших из активного сельскохозяйственного оборота [Agrojekologicheskoe sostojanie i perspektivy ispol'zovanija zemel' Rossii, vybyvshih iz aktivnogo sel'skohozjajstvennogo oborota]. Москва [Moskva]: Почв. ин-т им. В. В. Докучаева [Pochv. in-t im. V. V. Dokuchaeva]; 2008. p. 125–130.
6. Люри [Ljuri] ДИ [DI], Горячкин [Gorjachkin] СВ [SV], Короваева [Korovaeva] НА [NA]. Динамика сельскохозяйственных земель России в XX веке и постагрогенное восстановление растительности и почв [Dinamika sel'skohozjajstvennyh zemel' Rossii v XX veke i postagrogennoe vosstanovlenie rastitel'nosti i pochv]. Москва [Moskva]: ГЕОС [GEOS]; 2010.
7. Ramankutty N, Foley JA. Estimating historical changes in land cover: North American croplands from 1850 to 1992. Global Ecology and Biogeography. 1999;8:381–396. https://doi.org/10.1046/j.1365-2699.1999.00141.x
8. Allen EB, Cox RD, Tennant T, Kee SN, Deutschman DH. Landscape restoration in Southern California forblands: response of abandoned farmland to invasive annual grass control. Isr J Plant Sci. 2005;53:237–245. https://doi.org/10.1560/65LM-55YH-GB49-5BJM
9. Cramer V, Hobbs R, editors. Old fields: dynamics and restoration of abandoned farmland. Washington, DC: Island Press; 2007.
10. Блынская [Blynskaja] ТА [TA], Любова [Ljubova] СВ [SV], Кононов [Kononov] ОД [OD], Наквасина [Nakvasina] ЕН [EN]. Агроэкологическая оценка сельскохозяйственных угодий Архангельской области [Agrojekologicheskaja ocenka sel'skohozjajstvennyh ugodij Arhangel'skoj oblasti]. Архангельск [Arhangel'sk]: САФУ [SAFU]; 2013.
11. Антропова [Antropova] ГЕ [GE], Романов [Romanov] ЕМ [EM], Рохина [Rohina] ЕА [EA], Наквасина [Nakvasina] ЕН [EN]. Почвенный покров и агрохимическая характеристика почв Архангельской области [Pochvennyj pokrov i agrohimicheskaja harakteristika pochv Arhangel'skoj oblasti]. Достижения науки и техники АПК [Dostizhenija nauki i tehniki APK]. 2017;31(2):5–11.
12. Сорокина [Sorokina] ОА [OA], Токавчук [Tokavchuk] ВВ [VV]. Трансформация свойств серых почв зарастающих лесом залежей [Transformacija svojstv seryh pochv zarastajushhih lesom zalezhej]. In: Закономерности изменения почв при антропогенных воздействиях и регулирование состояния и функционирования почвенного покрова [Zakonomernosti izmenenija pochv pri antropogennyh vozdejstvijah i regulirovanie sostojanija i funkcionirovanija pochvennogo pokrova]. Москва [Moskva]: Почв. ин-т им. В. В. Докучаева [Pochv. in-t im. V. V. Dokuchaeva]; 2011. p. 512–519.
13. Rothero E, Lake S, Gowing D, editors. Floodplain meadows – beauty and utility. A technical handbook. Milton Keynes, Floodplain Meadows Partnership; 2016.

14. Котляков [Kotljakov] ВМ [VM], Люри [Ljuri] ДИ [DI], editors. Изменение природной среды России в XX веке [Izmenenie prirodnoj sredy Rossii v XX veke]. Москва [Moskva]: МОЛНЕТ [MOLNET]; 2012.
15. Kulmatiski A, Beard KH, Stark JM. Soil history as a primary control on plant invasion in abandoned agricultural fields. J Appl Ecol. 2006;43:868–876. https://doi.org/10.1111/j.1365-2664.2006.01192.x
16. Лайдинен [Lajdinen] ГФ [GF], Ларионова [Larionova] НП [NP], Лантратова [Lantratova] АС [AS]. Геоботаническое изучение луговой растительности [Geobotanicheskoe izuchenie lugovoj rastitel'nosti]. In: Методы полевых и лабораторных исследований растений и растительного покрова [Metody polevyh i laboratornyh issledovanij rastenij i rastitel'nogo pokrova]. Петрозаводск [Petrozavodsk]: ПетрГУ [PetrGU]; 2001. p. 243–257.
17. Паринова [Parinova] ТА [TA], Волков [Volkov] АГ [AG]. Методы изучения луговых экосистем: учебное пособие [Metody izuchenija lugovyh jekosistem: uchebnoe posobie]. Архангельск [Arhangel'sk]: КИРА [KIRA]; 2017.
18. Czerepanov SK. Vascular plants of Russia and adjacent states (the former USSR). Cambridge: Cambridge University Press; 2007.
19. Шишов [Shishov] ЛЛ [LL], Тонконогов [Tonkonogov] ВД [VD], Лебедева [Lebedeva] ИИ [II], Герасимова [Gerasimova] МИ [MI], editors. Классификация и диагностика почв России [Klassifikacija i diagnostika pochv Rossii]. Смоленск [Smolensk]: Ойкумена [Ojkumena]; 2004.
20. IUSS Working Group WRB. World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. Rome: FAO; 2014. (World Soil Resources Reports; vol 106).
21. Ганжара [Ganzhara] НФ [NF], Борисов [Borisov] БА [BA], Байбеков [Bajbekov] РФ [RF]. Практикум по почвоведению [Praktikum po pochvovedeniju]. Москва [Moskva]: Агроконсалт [Agrokonsalt]; 2002.
22. Наквасина [Nakvasina] ЕН [EN]. Агрохимические свойства почв: учебное пособие [Agrohimicheskie svojstva pochv: uchebnoe posobie]. Архангельск [Arhangel'sk]: АГТУ [AGTU]; 2009.
23. Edgington ES. Randomization testsed. New York, NY: Marcel Dekker; 1995.
24. Manly B. Randomization, bootstrap, and Monte-Carlo methods in biology. London: Chapman and Hall; 1997.
25. Fraker ME, Peacor SD. Statistical tests for biological interactions: a comparison of permutation tests and analysis of variance. Acta Oecol (Montrouge). 2008;33(1):66–72. https://doi.org/10.1016/j.actao.2007.09.001
26. Селезнев [Seleznev] СА [SA], Трофимов [Trofimov] ПМ [PM], editors. Архангельская область [Arhangel'skaja oblast']. Архангельск [Arhangel'sk]: Северо-Западное книжное изд-во [Severo-Zapadnoe knizhnoe izd-vo]; 1967.
27. Чалов [Chalov] РС [RS]. Русловые процессы и водные пути на реках бассейна Северной Двины [Ruslovye processy i vodnye puti na rekah bassejna Severnoj Dviny]. Москва [Moskva]: Журнал "РТ" [Zhurnal "RT"]; 2012.
28. Иванов [Ivanov] ДА [DA]. Луга и пастбища (Северо-западной зоны Нечерноземной полосы) [Luga i pastbishha (Severo-zapadnoj zony Nechernozemnoj polosy)]. Москва [Moskva]: Гос. изд-во с-х лит-ры [Gos. izd-vo s-h lit-ry]; 1953.
29. Паринова [Parinova] ТА [TA], Наквасина [Nakvasina] ЕН [EN], Сидорова [Sidorova] ОВ [OV]. Луга островной поймы низовий Северной Двины [Luga ostrovnoj pojmy nizovij Severnoj Dviny]. Архангельск [Arhangel'sk]: САФУ [SAFU]; 2013.
30. Варфоломеев [Varfolomeev] ЛА [LA], Цымбалюк [Cymbaljuk] ГА [GA]. Почвенно-земельный фонд Архангельской области как составляющая землепользования [Pochvenno-zemel'nyj fond Arhangel'skoj oblasti kak sostavljajushhaja zemlepol'zovanija]. In: Почва как природный ресурс Севера: материалы VII Сибирцевских чтений [Pochva kak prirodnyj resurs Severa: materialy VII Sibircevskih chtenij]. Архангельск [Arhangel'sk]: [publisher unknown]; 2005. p. 34–40.
31. Сорокина [Sorokina] НП [NP], Козлов [Kozlov] ДН [DN], Кузнецова [Kuznecova] ИВ [IV]. Влияние возраста вторичного леса на восстановление дерново-подзолистых почв бывшей пашни [Vlijanie vozrasta vtorichnogo lesa na vosstanovlenie dernovo-podzolistyh pochv byvshej pashni]. In: Лесные биогеоценозы Бореальной зоны: география, структура, функции, динамика [Lesnye biogeocenozy Boreal'noj zony: geografija, struktura, funkcii, dinamika]. Новосибирск [Novosibirsk]:

Изд-во СО РАН, [Izd-vo SO RAN]; 2014.

32. Голеусов [Goleusov] ПВ [PV], Набокова [Nabokova] ЕС [ES]. Формирование постагрогенного гумусововго горизонта в почвах залежных земель Белгородской области [Formirovanie postagrogennogo gumusovovgo gorizonta v pochvah zalezhnyh zemel' Belgorodskoj oblasti]. In: Proceedings: Проблемы природопользования и экологическая ситуация в Европейской России и сопредельных странах: Материалы V Международной научной конференции. [Problemy prirodopol'zovanija i jekologicheskaja situacija v Evropejskoj Rossii i sopredel'nyh stranah: Materialy V Mezhdunarodnoj nauchnoj konferencii]; 2013 Oct 28–31; Белгород [Belgorod], Russia. Москва [Moskva]: Министерство образования и науки РФ [Ministerstvo obrazovanija i nauki RF]: 2013. p. 245–248.
33. Романенко [Romanenko] ГА [GA], Иванов [Ivanov] АЛ [AL], Завалин [Zavalin] АА [AA]. Агроэкологическое состояние и перспективы использования земель России, выбывших из активного сельскохозяйственного оборота [Agrojekologicheskoe sostojanie i perspektivy ispol'zovanija zemel' Rossii, vybyvshih iz aktivnogo sel'skohozjajstvennogo oborota]. Москва [Moskva]: Росинформагротех [Rosinformagroteh]; 2008.
34. Baeten L, Velghe D, Vanhellemont M, de Frenne P, Hermy M, Verheyen K. Early trajectories of spontaneous vegetation recovery after intensive agricultural land use. Restor Ecol. 2010;18(52):379–386. https://doi.org/10.1111/j.1526-100X.2009.00627.x
35. Gibson DJ, Middleton BA, Foster K, Honu,YA, Hoyer EW, Mathis M. Species frequency dynamics in an old-field succession: effects of disturbance, fertilization and scale. J Veg Sci. 2005;16:415–422. https://doi.org/10.1111/j.1654-1103.2005.tb02381.x
36. Бобровский [Bobrovskij] МВ [MV], Комаров [Komarov] АС [AS], Шанин [Shanin] ВН [VN]. Моделирование динамики углерода почвы при различных системах традиционного земледелия и лесопользования на территории Европейской России [Modelirovanie dinamiki ugleroda pochvy pri razlichnyh sistemah tradicionnogo zemledelija i lesopol'zovanija na territorii Evropejskoj Rossii]. Известия Самарского научного центра РАН [Izvestija Samarskogo nauchnogo centra RAN]. 2009;1(7):1430–1434.
37. Китов [Kitov] МВ [MV], Григорьева [Grigor'eva] ОИ [OI], Цапков [Capkov] АН [AN]. О результатах оценки площади залежных земель в Белгородской области [O rezul'tatah ocenki ploshhadi zalezhnyh zemel' v Belgorodskoj oblasti]. Степной бюллетень [Stepnoj bjulleten']. 2006;46:29–35.
38. Prishchepov AV, Müller D, Dubinin M, Baumann M, Radeloff VC. Determinants of agricultural land abandonment in post-Soviet European Russia. Land Use Policy. 2013;30:873–884. https://doi.org/10.1016/j.landusepol.2012.06.011
39. Иванов [Ivanov] АЛ [AL], Волков [Volkov] СН [SN], Савин [Savin] ИЮ [IY]. Почвенно-экологические и инфраструктурные аспекты реализации стратегии развития агропроизводства в России [Pochvenno-jekologicheskie i infrastrukturnye aspekty realizacii strategii razvitija agroproizvodstva v Rossii]. Бюллетень Почвенного института им. В. В. Докучаева [Bjulleten' Pochvennogo instituta im. V. V. Dokuchaeva]. 2017;89:104–120. https://doi.org/10.19047/0136-1694-2017-89-104-120
40. Müller D, Prishchepov AV, Levers C, Kruhlov I, Kuemmerle T. Recultivation of abandoned agricultural lands in Ukraine: patterns and drivers Anatoliy Smaliychuka. Glob Environ Change. 2016;38:70–81. https://doi.org/10.1016/j.gloenvcha.2016.02.009

Modyfikacja gleb w chronosekwencji ekosystemów porolnych intrazonalnych gleb litogenicznych w obwodzie archangielskiego (Rosja)

Streszczenie

Przedmiotem badań w niniejszej pracy były procesy samoodnawiania gleb i ich modyfikacji w ekosystemach porolnych zlokalizowanych w obrębie intrazonalnych (zalewowych) gleb lasów borealnych. Analizowano powierzchnie na gruntach ornych (22 poletka badawcze) w delcie północnej Dwiny (rejonu primorskiego, obwodu archangielskiego, region, północno-zachodnia Rosja), które zostały wyłączone z użytkowania rolniczego w ciągu ostatnich 50 lat i które obecnie są w stadium zarastania. Jako stanowiska referencyjne wykorzystano pierwotne/wtórne łąki zalewowe z naturalnymi glebami zalewowymi. W wyniku badań stwierdzono stopniowe zmiany właściwości zalewowych gleb łąkowych. Zmiany w profilach glebowych oraz zmiany właściwości chemicznych warstwy ornej obserwowano podczas przywracania wyłączonych z uprawy pól. Gleby zalewowe w dorzeczu północnej Dwiny zajmują 4,8% powierzchni i charakteryzują się dużą

żyznością. W przeszłości były one wykorzystywane do produkcji rolniczej. Ekosystemy porolne w delcie północnej Dwiny mają tendencję do tworzenia naturalnych podmokłych gleb o różnym zasięgu i charakteryzują się krótszym okresem przywracania gleb do uprawy. Zasobność warstwy ornej utrzymuje się tutaj przez 20 lat. Przekształcenie łąk zalewowych w grunty do produkcji rolnej jest możliwy w ciągu 40 lat.