Agrogenic soil evolution of rice agrolandscapes

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\textbf{Abstract.} This paper describes soil chronosequence studies relating to fertility evolution of meadow-chernozemic (Gleyic Chernozem) soil of the Kuban region. The research has been conducted in the rice irrigation system of Krasnoarmeysky district, Krasnodar Krai. Over the course of 80 years with 12-year intervals, soil was sampled from pits from the plots/checks with permanent rice cultivation, or with crop rotation as well as from fallow land. Changes of morphological, physical and physico-chemical soil characteristics were studied. Rice paddy cultivation results in removal from the plow layer organic substances, carbonates, mineral elements, and silt particles, i.e. of the components responsible for stable soil development in the irrigation system. This illustrates the expression of dehumification, lessivage, and degradation soil processes with rice cultivation permanently as a monoculture or in a crop rotation during the chronosequence study. Deterioration of the soil physical condition is one of ever-increasing factors.

1. \textbf{Introduction}

Rice cultivation technology involves specific air and water regime of a rice paddy field that leads to the transformation of the soil profile morphology, degree of manifestation of diagnostic horizons due to the eluvial-gleization process and change of a range of physical and physical-chemical soil properties. While in black soils, used in rainfed agriculture, bio-accumulative processes are most typical, under conditions of flooded fields for rice cultivation eluvial and metamorphization processes are manifested, mostly gleization and compaction. Eluvial-gleization processes prevail in almost all rice field soils, whatever their genesis [1-7].

The goal of this research is to follow the trend of temporary changes of fertility values of meadow-chernozemic soil [8] in rice paddy conditions of the Kuban.

2. \textbf{Objects and methods}

The research has been made on a rice irrigation system of Elite Seed-Production Farm Krasnoye of Krasnoarmeysk District, Krasnodar Krai, on meadow-chernozemic soil [8] (corresponding to Gleyic Chernozem in WRB [9]). The effect of puddy cultivation on soil properties, regimes and processes was studied through comparison of current (2016) of the meadow-chernozemic soil with 2004 data. Within the rice irrigation system that had been working since 1937, soil samples were collected from representative profiles with 12-year intervals from the same plots.
Plot 1. Rice monoculture for 80 years, without nutrient application (45°14'0.67", N; 38°19'20.12", E). The soil is meadow-chernozemic (corresponding to Gleyic Chernozem in WRB), with low humus content, weakly leached, deep, clay loam on alluvial clays.

Plot 2. Rice cultivation in crop rotation under technology adopted by the farm by recommendation of the All-Russia Scientific Research Institute of Rice (45°13'54.98", N; 38°19'10.92", E). The soil is meadow-chernozemic (corresponding to Gleyic Chernozem in WRB), low-humic, weakly leached, deep, clay on alluvial clay sediments.

Plot 3. Fallow land on the rice irrigation system since the moment of its commencement, and has never been involved in the crop rotation (45°14'0.63", N; 38°19'36.28", E). The soil is meadow-chernozemic (corresponding to Gleyic Chernozem in WRB), low-humic, weakly leached, medium phased, clay loam on alluvial clay loam sediments.

The morphological characteristic of the soil has been made according to [10, 11, 12].

Analytical part of the research has been performed according to State standards of laboratory protocols in minimum two replications. Available phosphorus and potassium content was determined according to Chirikov method with acid extract 0.5 N CH₃COOH (pH 2.5) at a ratio of soil to solution 1: 25. Phosphorus in the extract was determined by photometric method and potassium by atomic absorption spectroscopy [13].

Carbon determination method of Tyurin was used for determination SOC content according to the modified Tyurin dichromate approach with wet combustion at 160°C for 30 min. Organic carbon content was established photometrically using glucose standards and converted to SOM content by multiplying the SOC content by the alteration factor 1.724 [14]. SOM stock was recalculated based on soil density, which was determined by the standard core cutter method in three replications in undisturbed core samples. The bulk density was calculated by the ratio of dry mass to volume at the determined water content and/or the specified water tension [9]. Exchangeable bases were extracted with 1 M ammonium acetate at pH 7. The individual cations in the leachate were analyzed by flame atomic absorption and flame emission spectrometry. The pH was measured in 1: 2.5 soil: water suspension potentiometrically [15, 16]. The group composition of soil humus was determined by using the accelerated pyrophosphate method according to Kononova and Belchikova [14].

Total nitrogen was determined by dry digestion in a Vario El III elemental. Labile carbon was determined by oxidation using dilute KMnO₄ solution as described by Blair [17]. The gas-volumetric determination of carbonate was in two replications according to Rowell [18].

Soil texture was determined by the standard pipette method with sodium pyrophosphate. Total porosity was recalculated from particle-size distribution and soil density [15, 16].

3. Results and discussion

The conducted research has highlighted transformations of the meadow-chernozemic soil properties during the cronosequence study. These changes are especially notable under conditions of continuous paddy rice as monoculture for 80 years. Hydragric features are characterized by abundant iron rust and ochroid spots, stains and rust fibers. Specific soil colour has a glaucoscent shade with coal-black spots of sulphidic compounds. Near the surface the soil especially the subsurface horizon, is considerably compacted, the horizon depth has increased by 3 cm due to organic matter mobility. Annual puddling of the rice field has led to degradation of cloddy-granular structure of the shallow horizons with a primary formation of cloddy and blocky aggregates. Displacement of effervescence line downward the soil profile due to dissolution of carbonates has been noted.

Under paddy rice in crop rotation changes of morphological properties of meadow-chernozem soil have been less prominent in comparison with the rice monoculture. 12 years of puddy cultivation led to a significant compaction of the subsurface horizon, deterioration of the soil structure and an increase of its depth (+ 4 cm) due to the removal of organic matter from the plowing layer. 4 cm decrease of effervescence line indicates removing of carbonates from the plowing horizon.

Over a 12-year period on the fallow land within the rice irrigation system, signs of hydromorphism in the soil increased but soil profile texture did not change. Compared with the previous period, there
has been found a large amount of cane rootstalks in soil profile with clusters of coal-black sulphidic cutans. Presence of sulphide was confirmed by chlorine hydride test.

However, despite the above mentioned changes meadow-chernozemic soil has preserved its key morphological properties, specific to each plot (figure 1).

Plots of meadow-chernozem soil with different management differ by particle-size distribution. Clay loam texture is characteristic of plots with puddy rice monoculture and fallow land, physical clay (particles < 0.01 mm) content 56.6 and 58.6 % respectively. Clay texture (68.7 % physical clay) is characteristic of plots with puddy rice in crop rotation. These differences are due to heterogeneity of parent material, represented by alluvial clays for rice rotation and monoculture and clay loams for fallow land plots. That characterizes fertility diversity for soils of the rice irrigation system in a certain way.

![Rice monoculture](image1)
![Rice cultivation in crop rotation](image2)
![Fallow land](image3)

**Figure 1.** Meadow-chernozem soil profile of the rice irrigation system (2016).

Continuous rice growing since 1937 without fertilizers application has significantly affected humus state of the meadow-chernozem soil (table 1). Processes of dehumification are prominent – humus content has decreased by 0.61 % (23.43 t/ha) alongside its fulvatization \( C_{\text{fu}}/C_{\text{hu}} = 0.84 \). Annual humus losses comprise 0.05 % (1.95 t/ha), total nitrogen content has decreased by 0.05 % or by a factor of 1.5 with C/N increase from 12 to 15. The greatest changes in humus content are noted in a first meter of soil profile. Removal of labile carbon from the plowing field into \( AB_1 \) horizon was noted.

Rice monoculture has prompted the rapid depletion of soil available phosphorus and potassium. Over 12 years the grade change was observed from poorly supplied to the very poorly supplied by phosphorus. Its removal from the plowing layer and displacement of accumulation zone from \( A_{\text{plow}} \) to \( AB_1 \) horizon has been noted.

Over a 12 year period the content of silt particles in the plowing horizon decreased from 28.9 to 27.7 %, which is due to their removal down the soil profile with the intensification of lessivage processes.
Sum of exchange bases has decreased by 8.4% with simultaneous replacing Ca\(^{2+}\) (decrease from 69.8 to 63.3% of exchange bases sum) and K\(^+\) (from 2.8 to 2.3%) in the soil adsorption complex by Mg\(^{2+}\) (increase from 23.3 to 29.2%). This has affected physical condition of the soil with high bulk density (1.59-1.66 g/cm\(^3\)) and excessive poor porosity (40.1-41.1%). pH value in A\(_{\text{plow}}\)+AB horizon decreased by 0.37 units, in the plowing horizon by 0.49 units, and content of carbonates in A\(_{\text{plow}}\) have decreased by factor of 1.8. Upper 73 cm of the soil profile is exposed to carbonate removal. Equivalent transformation of physical and physical-chemical fertility values of meadow-chernozemic soil over that period, but to a considerably lesser extent was revealed for paddy rice cultivation in crop rotation (table 1).

Over a 12-year period clay content in the plowing layer decreased from 42.4 to 40.8%, total humus content – by 0.08%, total nitrogen – by 0.017%, humus stock decreased by 4.15 t/ha, with average annual loss 0.35 t/ha, that is 5.5 times less than in rice monoculture. C/N rating, equaling 8, was stable. Deeper soil layers with comparatively smaller humus stocks have not demonstrated quantitative changes. It is important to highlight removal of labile carbon from the plowing layer to the subsurface horizon. Content of fulvic acids increased with simultaneous decrease of humic acids decreased with C\(_{\text{tot}}\)/C\(_{\text{la}}\) decrease from 1.97 to 1.87.

**Table 1. Change of chemical properties of the meadow-chernozem soil.** Bold values indicate significance at \(p < 0.05\).

| Plot                | Year | Horizon | Humus (%) | N\(_{\text{tot}}\) (%) | pH\(_{\text{aq}}\) (unit) | CaCO\(_3\) (%) | P\(_2\)O\(_5\) (mg/100 g) | K\(_2\)O (mg/100 g) |
|---------------------|------|---------|-----------|------------------------|------------------------|----------------|---------------------------|-------------------|
| Paddy rice monoculture | 2004 | A\(_{\text{plow}}\) | 2.88 | 0.139 | 6.55 | 0.44 | 2.77 | 20.20 |
|                     |      | A       | 2.53 | 0.095 | 7.48 | 0.62 | 10.04 | 18.67 |
|                     | 2016 | A\(_{\text{plow}}\) | 2.27 | 0.089 | 6.06 | 0.25 | 1.90 | 17.22 |
|                     |      | A       | 1.91 | 0.063 | 7.19 | 0.50 | 11.37 | 13.60 |
| Paddy rice in crop rotation | 2004 | A\(_{\text{plow}}\) | 3.12 | 0.227 | 6.84 | 0.38 | 3.73 | 24.40 |
|                     |      | A       | 3.01 | 0.181 | 7.20 | 0.53 | 7.30 | 13.88 |
|                     | 2016 | A\(_{\text{plow}}\) | 3.04 | 0.210 | 6.39 | 0.29 | 3.53 | 22.86 |
|                     |      | A       | 2.90 | 0.175 | 7.19 | 0.61 | 8.36 | 12.77 |
|                     | 2004 | A\(_{\text{plow}}\)+A | 3.78 | 0.357 | 7.67 | 0.70 | 18.14 | 46.61 |
|                     |      | AB      | 2.21 | 0.162 | 8.24 | 1.06 | 5.40 | 10.30 |
|                     | 2016 | A\(_{\text{plow}}\)+A | 4.71 | 0.438 | 7.48 | 0.60 | 20.82 | 52.01 |
|                     |      | AB      | 2.01 | 0.173 | 8.27 | 1.10 | 5.46 | 10.05 |

Available phosphorus and potassium content in the plowing horizon depleted significantly, but to a lesser extent than in rice monoculture. A tendency of available phosphorus accumulation is found in the horizon AB.

In the soil adsorption complex more drastic changes are found in the subsurface horizon, where Ca\(^{2+}\) content has decreased from 76.0 to 72.0% and Mg\(^{2+}\) has increased from 18.0 to 21.0% of the sum of exchange bases. Physical properties also reflect a degradation process – bulk density has increased from 1.34 to 1.41 g/cm\(^3\) and soil porosity decreased from 50.7 to 48.9%. pH value in A\(_{\text{plow}}\) has decreased by 0.45 units due to carbonate removal.

On the fallow land, content of silt particle decreases down the soil profile with absence of temporal dynamics. In a 12-year period total and water-soluble humus stocks, as well as total nitrogen, available
phosphorus and potassium content in the fallow land increased due to additional decomposition of crop residues in comparison with the cultivated areas (table 1).

The ratings $C_{p}/C_{a}$ were in the range 2.65-2.76 and C/N about 6. Both parameters varied weakly during the research period. pH value has decreased by 0.19 units, slight changes have occurred in the soil adsorption complex. Carbonate dissolution processes were found in the upper 30 cm layer.

4. Conclusion

Deterioration of the meadow-chernozemic soil physical conditions on the long-term paddy rice in monoculture, specifically, high density of plowing and subsurface horizons and, consequently, abnormally low porosity, compared to the paddy rice growing in crop rotation field, under which soil consolidation is manifested in the subsurface horizon, was found during 12-year chronosequence study. The diagnosed changes are due to removal of organic substances, carbonates, nutrients, silt particles as the components of soil stability over a long-term irrigation, and may reflect processes of dehumification, lessivage, chemical degradation, expressed in a paddy rice monoculture as well as in a paddy rice in crop rotation.

References

[1] Bahmanyar M A 2007 The Influence of Continuous Rice Cultivation and Different Waterlogging Periods on Morphology, Clay Mineralogy, Eh, pH and K in Paddy Soils Pakistan J. Biol. Sci. 10 2844-49

[2] Chacon N, Silver W L, Dubinsky E A and Gusack D F 2006 Iron reduction and soil phosphorus solubilization in humid tropical forest soils: the roles of labile carbon pools and an electron shuttle compound Biogeochemistry 78 67-84

[3] Gutorova O A and Sheudzhen A Kh 2016 Morphogenetic Features of Rice Meadow-Chernozemic Soil Russian Agricultural Sciences 42 353-56

[4] Gutorova O A and Sheudzhen A Kh 2017 Morphogenesis of Rice Meadow-Boggy Soils in Kuban River Region Russ. Agr. Sci. 43 40-43

[5] Huang L M, Thompson A, Zhang G L, Chen L M , Han G Z and Gong Z T 2015 The use of chronosequences in studies of paddy soil evolution: a review Geoderma 237-238 199-210

[6] Li Z P, Zhang T L, Li D C, Velde B and Han F X 2005 Changes in soil properties of paddy fields across a cultivation chronosequence in subtropical China Pedosphere 15 110-19

[7] Winkler P, Kaiser K, Kölbl A, Kühn T, Schad P, Urbanski P, Lehndorff E, Kalbitz K et al 2015 Response of Vertisols, Andosols, and Alisols to paddy management Geoderma 261 23-35

[8] Egorov V V, Fridland V M, Ivanova E N, Rozov N N, Nosin V A and Friev T A 1977 Classification and soil diagnostics of the USSR (Moscow: Kolos) p 221 (in Russian)

[9] World Reference Base for Soil Resources 2014. Update 2015. International soil classification system for naming soils and creating legends for soil maps World Soil Resources Reports No. 106 (Rome: FAO) p 192

[10] Rozanov B G 2004 Soil morphology (Moscow: Academic Project) p 432 (in Russian)

[11] Mikhailova E A and Post C J 2014 Laboratory exercises for Soil Judging: Second Edition (Paperback Amazon) p 108

[12] Świtoniak M, Kabała C, Karklins A, Charzyński P, Hulisz P, Mendyk Ł, Michalski A et al 2018 Guidelines for Soil Description and Classification Central and Eastern European Students’ Version (Polish Society of Soil Science Torun) p 286

[13] Sokolov A V 1975 Agrochemical Methods of Soil Examination (Moscow: Nauka) pp 106-90 (in Russian)

[14] Orlova N E, Bakina L G and Orlova E E 2007 Study methods of humus composition and content (Saint-Petersburg: Publishing of Saint-Petersburg University) p 145 (in Russian)

[15] Van Reeuwijk L P 2002 Procedures for soil analysis 6th Edition (Wageningen: International Soil Reference and Information Centre ISRIC) p 101
[16] Jackson M L 2005 *Soil Chemical Analysis: Advanced Course* (UW-Madison Libraries Parallel Press) p 930  
[17] Blair G J, Lefroy R DB and Lise L 1995 Soil Carbon Fractions Based on Their Degree of Oxidation, and the Development of a Carbon Management Index for Agricultural Systems *Aust. J. Agr. Res.* 46 1459-66  
[18] Rowell D L 1994 *Soil science: Methods & applications* (Longman Scientific & Technical, Longman Group UK Ltd, Harlow, Essex, UK) p 350