# Anthropogenic impact on grain-size distribution and agrophysical properties of soils of cultivated rice lands of Kuban

*A.V.* Osipov*, *V.N.* Slyusarev, *V.P.* Vlasenko, and *I.I.* Suminski

Federal State Budgetary Educational Institution of Higher Education "Kuban State Agricultural University named after I.T. Trubilin”

**Abstract.** This work reviews the relation of the grain-size distribution and impact of the use of rice rotation soils on the main agrophysical indicators of soils that determine the composition and properties of soil cover of modern delta of Kuban. The regularities of dependence between the density of the matrix soil and the grain-size distribution that consist of mineral composition of alluvial soils and rocks have been identified. The trend towards increase in soil density with increase in physical clay and silt content, as well as increase in matrix soil density has been established. No significant differences in agrophysical properties of subsurface soil horizons and underlying formations have been identified. The agrophysical indicators of soils of rice fields and boharic analogues during their agricultural use have been assessed. The hydromorphic soil-forming processes did not lead to considerable changes in agrophysical properties of alluvial formations and soils involved in rice rotation.

## 1 Introduction

This work is a result of many-year research of agrophysical properties of rice rotation soils. The need in such research is dictated by demands of the agricultural practice. Today it is not known how far are the conversion processes of agrophysical properties of former boharic soils that are currently used in rice rotation. At this, there arise the issues of development of methods for restoration of properties and fertility of the rice field soils.

Three massifs of the rice irrigation systems arranged on the first terrace above flood-plain, ancient delta and modern delta of Kuban river occupying more than 75% of total area of the rice systems that makes about 150 ths. ha are distinguished in the lower reach of Kuban river [1,3].

In this region, the characteristics of the parent rock materials and the soil cover of the rice systems are primarily dependent on geomorphology and relief.

The modern delta of Kuban, as the specific and the youngest geomorphological element of Kuban plains, occupies the area of about 6000 km$^2$ (600 ths. ha). The main elements of relief of the modern delta of Kuban are the ridge-shaped elevations along the acting and extinguished eriks, plain flat spaces and closed extensive flat depressions (limans) that were flooded for a

* Corrensponding author: kubsoil@mail.ru

long period of time during high-water periods. The absolute elevations of the region vary from 2-4 m to zero and even negative points.

The parent rock materials are represented by the modern alluvial formations of various grain-size distribution - from sands to heavy clays. In the western part of the region, the shell deposits are locally spread, they are the bystanders of the recent past when some part of the territory of the modern delta was a shallow gulf of the Se of Azov.

The ground waters in the considered region lay at the interval of 1-3 m, with their mineralization range from 0.5 g/l to 20-40 g-l and more.

Natural vegetation is represented by meadow, primarily, grass herbs in the uplands and by sedges and canes in the depressions. The pseudo-peat layer, the dead semidecomposed cane roots and stems, has formed along the bottom of limans, its thickness varies from 20 cm to 2 m.

The hydromorphous soils belonging to alluvial types have formed in the existing natural conditions: alluvial bog (humus-gley, slimy-peat-gley, slimy-peat), alluvial meadow-bog and alluvial meadow saturated (stratified, normal, black) soils [4,5,9].

The above listed soils are characterized by the presence of one or several buried soil horizons in the thickness of 0-2 m that evidences the intermittency of the soil-forming process and the youth of soils considered.

The elevated relief elements are made up by the deposits with light grain size distribution, primarily, by sand loams, loamy light sands and medium-textured loams with sand interlayers. The clayey deposits and, respectively, the clayey soils are most common in depressions and former limans.

The absence of fractions coarser than 1 mm in the grain size distribution should be noted as a general feature of deposits and soils of the region under consideration.

## 2 Materials and methods

Considering that the prevailing area of soils involved in rice rotation of the lower reach of Kuban river are located in the modern delta, the agrophysical properties of soils were studied for this geomorphological region.

The thickness of 1.6-2.0 m was researched during study of the agrophysical properties, considering small thickness of humus horizons of 30-60 cm, the researches covered considerable thickness of the parent rock materials. It was found out that no significant differences in agrophysical properties of subsurface soil horizons and underlying formations were observed. It follows that the hydromorphic soil-forming processes did not lead to considerable changes in agrophysical properties of alluvial formations that is related to the youth of the soils under consideration. The duration of the soil-forming process that is repeatedly discontinued by the buried formed soils, fresh alluvial sediments, does not exceed 2-4 thousand years in this region [2].

The basis for the summary were the materials of research of the physical properties of soils carried out in this region in 2008–2020. 110 points were researched according to the unified procedure in the field and laboratory conditions to study the agrophysical properties of soils that made it possible to use the statistical data processing methods and assess their reliability.

## 3 Results and discussion

The research of the agrophysical properties of soils in different regions of Krasnodar Territory showed that the identified varieties considerably differ by their agrophysical properties that, to a great extent, determines the genesis of the parent rock materials.

Three groups of the parent rock materials and the soils with various agrophysical properties formed on their basis, having the similar grain size distribution, that is the physical clay and physical sand ratio, can be distinguished in the initial approximation in Krasnodar Territory:

- loesslike deposits and formed zonal soils of chernozem type that are characterized by high porosity and fluffy consistency;
- alluvial deposits with hydromorphous soils, with average density and porosity;
- degraded loesslike, deluvial, tertiary marine deposits and saline soils with zonal and intrazonal soils that characterized by high density and low porosity [4,6].

Within the mentioned soil groups, the same varieties of the grain size distribution have rather closely adjacent indicators of the agrophysical properties. With the same genesis of the parent rock materials, depending on the soil-forming and other natural processes (subsidence, compactness, salinization, gleyzation, etc.), the agrophysical properties can be considerably different while having the same grain size distribution [11,12]. The comparison of agrophysical properties of soils of different genesis is given (table 1).

**Table 1.** Grain size distribution and agrophysical properties of subsurface horizons of various types of soils.

| Indicators of soil composition and properties | Ordinary chernozem | Meadow chernozem soils | Alluvial meadow soils |
|---|---|---|---|
| Physical clay content, % | 61 | 61 | 67 |
| Silt content, % | 30 | 34 | 26 |
| Silt/dust ratio | 1.0 | 1.3 | 0.6 |
| Solid phase density, g/cm$^3$ | 2.70 | 2.70 | 2.74 |
| Bulk density, g/cm$^3$ | 1.33 | 1.57 | 1.34 |
| Total porosity, % | 50.7 | 41.9 | 51.1 |
| Aeration porosity, % | 15.7 | 3.7 | 10.6 |

The comparison of basic indicators of the agrophysical properties of various types of soils with the same grain size distribution evidences significant difference by the soil bulk density and aeration porosity.

In the modern delta of Kuban, the difference by basic indicators of the agrophysical properties is observed from the steppe zone of the Territory where the parent rock materials are the loesslike deposits that are relatively homogeneous by their grain size distribution, and in the delta of Kuban, the considerable area of the soil cover with the homogeneous grain size distribution makes an exception. Confinedness of the light soils to the uplands and of the heavy soils to the depressions, commonly occurring stratification - the interleave of layers with various grain size distribution that is not smoothed by the relatively short soil-forming process.

Construction of the rice irrigation systems and introduction of rice rotation delineated the soil-forming processes of the rice agrocoenosis and boharic analogues. The alluvial meadow boharic soils began adapting to the steppe conditions, and the soils used in rice rotation of various original genesis began developing in the artificially created meadow-boggy conditions. But the differences in the soil processes actually have not affected the stable indicator - the grain size distribution, no pronounced difference in the grain size distribution of the soils involved in the rice rotation and boharic soils has been identified.

The soils of the rice agrocoenosis of the modern delta are irrigated by Kuban water that carries the silty suspended matters and leaves them in the soil. This would seem to have great impact on the silt content in these soils [10].

After construction of the Krasnodar water reservoir, Kuban water began leaving more than 90% of the carried suspended matters in its bed. In the tail race of the water reservoir, the silt content in Kuban water makes 20–30 g/m$^3$ in total. But downstream, near Fedorovsky and Tikhovsky hydrosystems feeding the rice irrigation systems of the modern delta, the silt amount in water increases to 50–100 g/m$^3$ due to bank erosion. With the average irrigation norm for rice of about 12 ths. m$^3$/ha, about 0.7–1.3 t/ha of silt penetrates the soil.

The silt carried by irrigating waters is actually distributed only in the ploughing horizon of the soil, and its inflow can be calculated in % relative to initial silt content. With the average soil density of about 1.4 g/cm$^3$, the weight of the ploughing horizon makes: 10000x0.24x1.4 ≈ 3500 t/ha. Its silt content is usually 20-40%, or 700–1400 t/ha. The annual silt inflow by irrigating waters makes 1/1000, or 0.1 % of the initial content. At least 100 years of annual rice-on-rice cultivation will be required in order the heaving of the grain size distribution of the rice field soils is practically noticeable due to the silt inflow by irrigating waters, this heaving process of soils is slow and virtually is not pronounced [13].

The analysis of the research made it possible to establish the leading role in the quantitative indicators of the physical clay composition, namely, its silt fraction content (<0.001mm particles) or the silt/dust ratio (0.01–0.001mm particles). By these indicators, the above described three types of soils differ significantly within the same variety of the grain size distribution. The silt/dust ratio can be a powerful tool in the study and quantification of the water-physical properties in the physical realm. It is noted that the relative silt fraction content is determined not only by the parameters of the water-physical properties, but also by such agrochemical properties as the amount and composition of the absorption capacity, reserves and forms of mobile nutrients, humus content and composition.

The boharic soils and rice rotation soils of the modern delta of Kuban formed on the alluvial deposits showed a regular increase in the silt/dust ratio as the grain size distribution increases, that is, as the physical clay content increases. The statistical processing of the grain size distribution data made it possible to identify average values of the silt/dust ratio for all soil varieties by the grain size distribution (Table 2).

**Table 2.** Dependence of the silt content and the silt/dust ratio on the physical clay content in soils and alluvial deposits of the modern delta of Kuban.

| Soil varieties by grain size distribution | Physical clay content, % (PC) | Silt content, % (s) | Dust content, % (d) | Silt/dust ratio Csd | Silt content, %, of the physical clay content, S |
|---|---|---|---|---|---|
| Sandy | < 10 | < 1 | > 9 | < 0.1 | < 10 |
| Sandy loam | 10-20 | 1-3 | 9-17 | 0.1-0.18 | 10-15 |
| Light loamy | 20-30 | 3-6 | 17-24 | 018-0.23 | 15-20 |
| Middle loamy | 30-45 | 6-12 | 24-33 | 0.25-0.36 | 20-27 |
| Heavy loamy | 45-60 | 12-21 | 33-40 | 0.36-0.50 | 27-35 |
| Light clay | 60-75 | 21-31 | 40-44 | 0.50-0.70 | 35-42 |
| Middle loamy | 75-85 | 31-41 | ≤ 44 | 0.70-0.93 | 42-48 |
| Heavy clay | > 85 | 41-56 | ≤ 44 | 0.93-1.27 | 48-55 |

The given dependence of the silt/dust ratio (Csd) on the physical clay (PC) content has the graphical representation of the exponent and is quite detailed by the empirical equation:

$$Csd=\mathbf{e}^{[PC/40-2.2]}, \quad (1)$$

it follows from the formula (1):

$$LnCsd = (PC : 40) – 2,2, \quad (2)$$

$$PC = (Ln\ Csd + 2,2)\ to\ 40, \quad (3)$$

where **e** is the base of the natural logarithm;

Ln is the natural logarithm.

The dependence of the silt content in % on the physical clay content has is simpler - the view of arithmetic progression (straight line in the graph), and is expressed as the equation:

$$S = (0.5\ PC + 5), \quad (4)$$

where S is the silt content, %, of the physical clay (PC) content.

It follows from the above:

- each kind of the grain size distribution of the soils being considered corresponds to specific and rather narrow silt/dust ratio;
- the silt content in each kind of the grain size distribution is determined by the physical clay content;
- the quantitative change in the physical clay content corresponds to the qualitative change in its composition, namely, its silt content.

The density indicator of the matrix soil is the most stable over time and is taken as constant in the relevant calculations. In the soils being considered, it varies within a wide range from 2.46 (in grained sands) to 2.78 g/cm$^3$ (in heavy clays). The research made it possible to identify the conformity of each kind of the grain size distribution and certain density indicators of the matrix soil and their variation within the narrow range (Table 3).

**Table 3.** Dependence of the matrix density and the bulk density of soils on the physical clay content

| Soil varieties by grain size distribution | Physical clay content, % (PC) | Matrix soil density, g/cm$^3$ (d) | Soil density variation limits, g/cm$^3$ ($d_v$) |
|---|---|---|---|
| Sandy | < 10 | 2.46-2.62 | 1.08-1.42 |
| Sandy loam | 10-20 | 2.62-2.66 | 1.16-1.43 |
| Light loamy | 20-30 | 2.66-2.68 | 1.17-1.43 |
| Middle loamy | 30-45 | 2.68-2.71 | 1.19-1.44 |
| Heavy loamy | 45-60 | 2.71-2.73 | 1.22-1.46 |
| Light clay | 60-75 | 2.73-2.75 | 1.25-1.50 |
| Middle loamy | 75-85 | 2.75-2.76 | 1.30-1.55 |
| Heavy clay | > 85 | 2.76-2.78 | 1.40-1.62 |

The dependence of the matrix soil density on the physical clay content has the form is graphically represented as exponent. It is described by empirical equations rather detailed:

$$d = e^{(LnPC+36) : 40}, \quad (5)$$

$$40Ln\ d = (LnPC+36), \quad (6)$$

where: Ln is the natural logarithm, e is the base of the natural logarithm.

The dependence of the matrix soil density on the physical clay content, particularly, on the silt/dust ratio is also graphically represented as exponent and described by the empirical equation:

$$d = 2,766 + (Ln\ Csd : 16), \quad (7)$$

It follows from the equation (7):

$$Csd = e^{(d - 2.768)/16}, \tag{8}$$

In equations (5–8), the following units are used:
PC – in %, Csd – in unit fractions, d – in g/cm$^3$.

The mentioned equations are produced on the basis of the summarized definitions of the matrix soil density and grain size distribution, and are of static nature. The deviation of the obtained results of the matrix soil density from those calculated by equations 5 and 7 should be regarded as an anomaly that requires detailed consideration.

The given equations make it possible to calculate the matrix soil density with sufficient accuracy ($P \geq 85\%$) according to the grain size distribution data. This is of practical importance, the grain size distribution analyzes are usually performed in large quantities, density determinations in small volumes.

The physical significance and essence of the identified regularities of dependence between the matrix soil density and the grain-size distribution of soils consist in mineral composition of alluvial soils and rock. The physical clay is a component that includes complex high molecular weight minerals with a density of 2.7-5.2 g/cm$^3$ - muscovites and biotites, hornblendes and augites, hydrohematites and various iron compounds (hematite, limonite, magnetite), etc. The physical sand mainly includes simpler compounds with a density of 2.4-2.6 g/cm$^3$ - quartz, kaolinite, orthoclase, microcline, etc. As the physical clay content and silt content in soils increase, the matrix soil density increases proportionally, and vice versa, as the physical sand content increases, the matrix soil density decreases.

The soil bulk density is of the most important characteristics of the agrophysical indicators of soils determining the other indicators - porosity, water capacity, water yield and permeability.

The soil bulk density is not constant, it is subject to seasonal cyclic changes in the boharic conditions, when its minimum values correspond to the spring disequilibrium state of the soil, and its maximum values correspond to the autumn disequilibrium state, and also the unstable water regime leads to significant dynamics of soil density between the indicated seasons [14].

Determination of the density of soils of the same genesis and the grain size distribution with the various natural moisture content gave widely different results. Therefore, during the statistical processing of the density data, we used its values obtained with the moisture content being equal to the lowest water capacity (WC). It should be noted that if the soil had a tendency to swell, this property was manifested to a great extent with the moisture content being equal to the WC. Despite the indicated limitation on moisture content, the variation in the density values of soils with the same grain size distribution was significant. This is related to the study of the agrophysical properties during the entire warm period of the year (from April till October), when there were seasonal changes in the water-physical properties.

Statistical processing of such dynamic values without appropriate ranking is incorrect, and in this case, it is possible statistically to substantiate the limits of variation (min - max) in (Table 3).

Based on the given data, there is a trend towards increase in soil density with increase in physical clay and silt content, as well as increase in matrix soil density. But the listed characteristics are stable over time in contrast to the soil density. That's why, there can be no clear dependence of Y on PC, silt and matrix soil expressed in mathematical terms.

Large bulk of initial data made it possible to identify an equally important regularity: with the relatively homogeneous grain size distribution of soils, a clear tendency to increase in the bulk density in depth is revealed (Table 4).

**Table 4.** Change in average density along the profile of alluvial meadow soils of the modern delta of Kuban

| Averaged thickness of genetic horizons, cm | Clay content, % | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | < 10 | 10-20 | 20-30 | 30-45 | 45-60 | 60-75 | 75-85 | > 85 |
| | Bulk density, g/cm$^3$ | | | | | | | |
| 0-23 | < 1.15 | < 1.16 | < 1.22 | < 1.19 | < 1.22 | < 1.25 | < 1.30 | < 1.40 |
| 23-45 | 1.15-1.24 | 1.16-1.25 | 1.22-1.30 | 1.19-1.28 | 1.22-1.30 | 1.25-1.34 | 1.30-1.40 | 1.40-1.45 |
| 45-70 | 1.24-1.32 | 1.25-1.32 | 1.30-1.37 | 1.28-1.35 | 1.30-1.37 | 1.34-1.41 | 1.40-1.48 | 1.45-1.52 |
| 70-100 | 1.32-1.37 | 1.32-1.38 | 1.37-1.42 | 1.35-1.40 | 1.37-1.42 | 1.41-1.45 | 1.48-1.52 | 1.52-1.57 |
| 100-150 | 1.37-1.41 | 1.38-1.42 | 1.42-1.45 | 1.40-1.43 | 1.42-1.45 | 1.45-1.48 | 1.52-1.54 | 1.57-1.61 |
| 150-200 | 1.41-1.42 | 1.42-1.43 | 1.45-1.46 | 1.43-1.44 | 1.45-1.46 | 1.48-1.50 | 1.54-1.55 | 1.61-1.62 |

According to the Modin's soil compaction estimation scale [7], the density of soils with the sandy, light loamy and middle loamy grain size distribution during the vegetation period (May-September) is estimated as from very loose to medium dense, with the light and middle clay grain size distribution - from loose to dense, with the heavy clay grain size distribution - from medium dense to very dense, and the ploughing horizons of soils with all varieties of the grain size distribution are naturally characterized by the least density values.

## 4 Conclusion

The main agrophysical indicators and the grain-size distribution of the cultivated rice lands of the modern delta of Kuban differ from the steppe zone of the Territory, this difference depends on the relief elements and the parent rock material composition. Confinedness of the light soils to the uplands and of the heavy soils to the depressions, commonly occurring stratification, as well as the interleave of layers with various grain size distribution.

The introduction of rice rotation after construction of rice irrigation systems delineated the soil-forming processes of the rice agrocoenosis and boharic analogues but did not affect the stable indicator - the grain-size distribution. The regularities of dependence between the density of the matrix soil and the grain-size distribution that depend on the mineral composition of alluvial soils and rocks have been identified. The increase in bulk density of the rice field soils is observed with the increase in physical clay and silt content, as well as increase in matrix soil density.

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