Agrophysical properties of black soils depending on types of economic use in the Krasnoyarsk forest-steppe

S E Badmaeva, Yu V Badmaeva and V V Semenova
Krasnoyarsk State Agrarian University 90, Mira street, Krasnoyarsk, Russian Federation

E-mail: s.bad55@mail.ru

Abstract. About 50% of the world’s distribution of the richest soils on the planet, black soil, is concentrated in Russia. On black soil, 75% of the gross output of grain crops and 50% of livestock production are manufactured. However, the current state of black soils causes concerns about the increasing degradation that threatens Russia's food security. Black soils are a subject to significant anthropogenic stress; first of all they are exposed to agricultural impact. The problem of degradation of arable black soils is largely due to the deterioration of agrophysical properties and the degree of degradation varies in different soil-climatic zones. The granulometric compositions, density of soil structure, general porosity and water permeability depend on the nature of the soil use. Throughout the entire range of the studied agrophysical soils properties, arable black soils are inferior to virgin analogues located in similar conditions of the landscape. Post-irrigative soils transformed into a set aside are inferior in their agrophysical properties to virgin analogue, but surpass arable soils in some indicators. The range of unfavourable properties of black soils acquired as a result of irrigation is quite wide and manifests itself at almost all levels of their structural organization. It should be noted that irrigation with ecologically safe irrigation norms of 300 m³/ha does not impair the physical properties of the soil, in contrast to heavy irrigation norms, that determine the unidirectional and noticeable expression of the main indicators in the direction of their deterioration.

1. Introduction
The involvement of black soils in irrigated agriculture changes the soil-forming process [1,2,4-7,12]. Being distinguished by the high fertility, black soils are at the same time extremely sensitive to changes in the water regime. The irrational irrigation can lead to a rapid deterioration of their ameliorative state and loss of fertile properties. In Siberian conditions, the most fertile soils (black soils) are formed under natural conditions with a compensated hydrothermal mode, characterized by the ratio R/Qc = 0.8-1.1, where R is a radiation balance of the active surface, kcal / cm² / year; Qc is the amount of heat required for evaporation of precipitation, kcal / cm² / year, into account that this ratio of water and thermal resources is optimal from the point of view of soil processes and, based on the characteristics of the water-physical and chemical properties of black soils, irrigation should compensate for the deficit of precipitation per year of optimal natural moisture, i.e. when the ratio λ/(Qc + M) does not exceed 0.8-1.1 (M is the irrigation rate), and the soil water retention does not exceed 0.1 of the total evaporation.

In recent years, large areas of irrigated soils in Russia are not watered, transferred to dryland farming or sets aside, to the so-called post-irrigation soils. In the post-irrigation period in the former arable soil
horizons, there is a positive trend in the agronomical valuable aggregates, an increase in the water permeability and structure of the aggregates. One can note a decrease in density in the arable land horizons of all studied soils [9,10,11,14].

2. Description of the object of research

The objects of research are located on the territory of the municipality “Novoselovsky” in the zone of open forest-steppe and steppe in the south of the Krasnoyarsk Territory in the Minusinsk hollow. Agricultural land in the territory of the municipality occupies 248,206 hectares. The relief is characterized by irregularity. In the eastern part of the territory, the relief is depleted by erosion and denudation, and they represent cuesta forms in the configuration of ridges. The northern part of the territory is represented by gentle slopes, and the southern - steep. The southwestern part of the terrain is elevated and there are separate mountain peaks in the form of large hills, and the northwestern part is represented by a maned and ridged relief. The soil is eroded, contributing to water erosion on lowered elements of the relief, on logs and glossy-like terrain. The western and southwestern slopes, as the most wind-shock ones are exposed to the deflations.

Soil-forming rocks are depositions of middle and upper Devonian of Quaternary age. The Devonian aquifer complex is characterized by the ubiquitous distribution and unfavorable feeding conditions caused by the development of cuesto-ridge relief, that ensures the formation of surface runoff without the infiltration of moisture from precipitation. The eluvial-deluvial depositions are the most developed of the quaternary distributed everywhere. They are represented by loamy and woody rubbly soils. Their thickness is not constant and ranges from 1.5 m. to 29 m. Loamy soils are non-resistant. They are characterized by high porosity, prone to subsidence.

Flora is represented by plants typical for forest-steppe. The forested area is rather significant. Forests are located in floodplains, ravines and on the slope of ridges they are located in small arrays, cleaving. Natural grassy plants are preserved in the logs, along the sloping, steep hillside and ridges, and in the flood plain of the Chulym River. The grasscanopy is cereal-herbaceous covered with such representatives as meadow fescue, bluegrass, foxtail, red clover, astragalus, mouse peas, rank, meadowsweet, frying, Siberian sainfoin, meadow geranium, etc.

The hydrographic network is represented by the following rivers: Chulym, Krasnoyarsk Reservoir (Yenisei River), small rivers Anash, Kullog, Kama, Kozyn-dzhul, Beskish 0.8–6 m. wide and up to 0.5 m. deep. The location of the types and subtypes of the soils corresponds to the lie of the ground.

The monitoring studies were conducted on key areas of the “Novoselovo” hospital located in the forest-steppe zone on the typical black soils, formed on loess-like loams of the Quaternary depositions. The agophysical properties of typical black soils (granulometric structure, addition density, total porosity, water permeability) of different types of economic use (virgin land, arable land and post-irrigated) were studied in the period from 1997 to 2017 using generally accepted methods of soil research [3, 8, 13]. Statistical processing of single-factor and two-factor experiments was performed using the SPSS software package.

Within the studied territory, typical black soils have mainly medium and heavy loamy structure with an insignificant level of the skeleton (0-1%).

In typical black topsoil, the highest content of physical clay is noted in the upper soil horizons. A variegated granulometric structure is marked throughout the soil profile. The amount of physical clay within 123 cm of thickness varies from 23 to 58%, silt - from 10 to 23%. Starting from a depth of 62 cm there is a sharp decrease in the structure of physical clay. Soils are clearly differentiated into three layers according to the level of physical clay: in the 0-32 cm layer there is 49.6 - 52.4% physical clay; in the 34-52 cm layer it is 21.9%; in the 62-123 cm layer it is from 10.4 to 11.2%. In the half-meter layer of soil, up to the transitional horizon of the Armed Forces, the level of the sandy fraction ranges from 12.3 to 14.5%. According to the amount of sand fraction, an increase occurs down the soil profile, which is probably related not to the processes of soil formation but to the diversity of rocks where these soil types were formed (table 1).
Table 1. Granulometric structure of typical black soils (arable soils).

| Horizon | Depth, cm | Fraction size, % |
|---------|-----------|-----------------|
|         |           | >0.25 | 0.25-0.05 | 0.05-0.01 | 0.01-0.005 | 0.005-0.001 | <0.001 |
| A       | 0-25      | 13.1  | 16.5     | 20.8      | 12.6       | 13.5       | 23.5  |
| AB_v    | 26-32     | 14.5  | 14.7     | 18.4      | 14.2       | 15.6       | 22.6  |
| B_v     | 34-45     | 12.4  | 14.5     | 15.6      | 17.1       | 18.4       | 22.0  |
| BC_k    | 46-52     | 12.3  | 14.9     | 15.2      | 17.0       | 18.8       | 21.8  |
| C_k     | 62-89     | 19.9  | 21.5     | 24.6      | 12.1       | 11.5       | 10.4  |
| C       | 110-123   | 25.6  | 39.9     | 11.6      | 3.8        | 7.9        | 11.2  |

The level of coarse dust fractions in a half-meter soil layer decreases down according to the profile, while the fractions of medium and fine dust tend to increase in the same soil layer.

At the irrigation plots, the level of the clay fraction in the upper soil horizons was significantly less than in dryland farming. The analysis of the particle size distribution shows that long-term irrigation has led to the migration of the clay fraction down the profile. The level of the clay fraction in the 0-45 cm layer is from 15.2 to 16.9%. It is by 6.6% less than it is in arable soils. Then, in the soil layer of 46-62 cm, there is a sharp increase in the clay fraction up to 26.2%, and in the underlying soil horizons. This indicator was observed to fall up to 10.4–11.2%. In general, the level of physical clay in horizons A, B ranges from 38.3 to 45.7%, with a decrease in the level of this fraction up to 32-33.3%.

Table 2 presents the results of the analysis of the particle size distribution of the soils of the post-irrigation area.

Table 2. Granulometric structure of typical black soil (post-irrigation).

| Horizon | Depth, cm | Fraction size, % |
|---------|-----------|-----------------|
|         |           | >0.25 | 0.25-0.05 | 0.05-0.01 | 0.01-0.005 | 0.005-0.001 | <0.001 |
| A       | 0-25      | 17.2  | 19.1     | 21.4      | 14.8       | 12.3       | 15.2  |
| AB_v    | 26-32     | 16.6  | 18.6     | 20.6      | 15.8       | 12.3       | 16.1  |
| B_v     | 34-45     | 14.4  | 19.0     | 20.9      | 15.4       | 13.4       | 16.9  |
| BC_k    | 46-52     | 16.2  | 16.3     | 19.3      | 11.9       | 10.1       | 26.2  |
| C_k     | 62-89     | 20.2  | 22.5     | 25.3      | 12.4       | 10.2       | 9.4   |
| C       | 110-123   | 24.3  | 21.4     | 21.0      | 13.1       | 10.4       | 9.8   |

The sand fraction is 36.3% of the total structure of the soil size distribution in the upper 0-25 cm soil layer. The sandy fraction ends to increase down the soil profile. If in layers of 0-45 cm of soil, this fraction is 14.4-17.2%, then in the lower it is 20.2-24.3%. The level of dust fractions in the topsoil is 48.5%, and the share of fine dust is 12.3%. The change in the level of dust fractions up to 45 cm of the soil layer is insignificant. The highest level of the clay fraction was found in the soil layer 46-52 cm; it is 26.2%. Thus, the clay fraction, as the most dynamic, migrates down the profile with infiltrating water.

We have conducted the investigation of changes in the density of the addition of the studied soils from different economic uses. In virgin land soils, there are no any significant changes in the density of addition in time and is a peculiar value for this type of soil. The same trend in time is maintained on old arable land. In the post-irrigation areas, the density of addition in the upper 0-20 cm soil layer is 1.25 g / cm3, and in the lower soil layers there is a slight increase in this indicator. The effect of irrigation on the density of addition of the studied soils is associated with irrigation norms. As can be seen from table 3, the irrigation with heavy irrigation norms leads to compaction of the root zone soil.
The main reason for the deterioration of the absorption rate at all observation intervals was established, but the greatest decrease in the maximum values of water permeability was observed in the first hour of observation. The water permeability rate for 6 hours of observations decreases as follows: 3.3 mm / min at the sixth hour.

Compared with the corresponding analogues, the water permeability rate for 6 hours of observations decreases in 1.2 - 2.1 times. The ratio of the maximum values of water permeability to the minimum ones increases to 2.2 - 2.5. The variation of the absorption rate at all observation intervals was established, but the greatest decrease in the absorption rate is characteristic in the first hour of observation. The main reason for the deterioration of water permeability is characteristic in the first hour of observation. The water permeability rate for 6 hours of observations decreases as follows: 3.3 mm / min at the sixth hour.

Watering at a rate of 300 m$^3$/ha does not affect the structure of the root zone of the soil; moreover, it contributes to a decrease in the density of addition, which is apparently due to the improvement of the structural condition of the soil under perennial legume-grass mixtures. Irrigation rates of 500 m$^3$/ha and 700 m$^3$/ha cause adverse physical properties of the soil, which leads to more noticeable soil compaction.

The overall soil porosity is influenced, first of all, by the structure of the soil: the more structural the soil, the greater the total porosity (since, in addition to the enclosed pores, these soils have gaps between the structural units). Any destruction of the soil structure, which occurs as a result of the impact on the soil of natural and anthropogenic factors or as a result of improper tillage of the soil, leads to a decrease in total soil porosity. One can see in table 4, the total porosity has the best indicators in the upper horizons of the soil in virgin lands, arable lands and irrigated soils with the irrigation rate of 300 m$^3$/ha and in the classification of N.A. Kachinsky (1970) is characterized as “excellent”. Such high values of the total porosity are peculiarities of soils with a high content of organic matter. Rather high values of total porosity are peculiarities of the soils of the washing-out area (49.8% in a layer of 20-40 cm, 52.1% in the upper layer).

### Table 3. Changes in the density of the addition of typical black soil of various economic uses, g / cm$^3$.

| Terms of research | Layer, cm | Virgin lands | Arable lands | Post-irrigation | Irrigation 300 m$^3$/ha | 500 m$^3$/ha | 700 m$^3$/ha |
|-------------------|-----------|--------------|--------------|----------------|------------------------|-------------|-------------|
| 1997              | 0-20      | 1.13         | 1.06         | -              | 1.09                   | 1.21        | 1.31        |
|                   | 20-40     | 1.17         | 1.11         | -              | 1.12                   | 1.23        | 1.34        |
| 2017              | 0-20      | 1.14         | 1.07         | 1.25           | 1.08                   | 1.24        | 1.32        |
|                   | 20-40     | 1.17         | 1.13         | 1.29           | 1.13                   | 1.25        | 1.36        |

Watering at a rate of 300 m$^3$/ha does not affect the structure of the root zone of the soil; moreover, it contributes to a decrease in the density of addition, which is apparently due to the improvement of the structural condition of the soil under perennial legume-grass mixtures. Irrigation rates of 500 m$^3$/ha and 700 m$^3$/ha cause adverse physical properties of the soil, which leads to more noticeable soil compaction.

### Table 4. Change in total porosity of typical black soils, %.

| Terms of research | Layer, cm | Virgin lands | Arable lands | Post-irrigation | Irrigation 300 m$^3$/ha | 500 m$^3$/ha | 700 m$^3$/ha |
|-------------------|-----------|--------------|--------------|----------------|------------------------|-------------|-------------|
| 1997              | 0-20      | 55.8         | 57.6         | -              | 57.2                   | 51.8        | 47.3        |
|                   | 20-40     | 51.3         | 55.2         | -              | 54.9                   | 50.4        | 46.1        |
| 2017              | 0-20      | 55.2         | 56.9         | 52.1           | 57.8                   | 50.2        | 45.6        |
|                   | 20-40     | 51.9         | 53.3         | 49.8           | 53.9                   | 49.5        | 44.1        |

With a watering rate of 500 m$^3$/ha, the total porosity in the 0-20 and 20-40 cm soil layers is 50.2; 51.8% and 49.5; 50.2 and goes into a “satisfactory” gradation, at a rate of 700 m$^3$/ha it is “unsatisfactory.”

Water permeability is one of the most important hydrological characteristics of the soil, especially in the irrigated agriculture. Virgin black soils, possessing excellent structural and aggregate composition and favorable physical properties, are characterized by optimal indicators of water permeability. In our experiments, as a reflection of physical parameters, the changes in water permeability are noticeable with non-pressure absorption i.e., the speed was characterized by low dynamism in space and time and varied from 4.9 to 5.6 mm / min in the first hour and to 2.9-3.3 mm / min at the sixth hour. On arable black soils, in the first hour of observations, the water permeability decreases from 3.4 mm / min to 2.9 mm / min, and by the end of the observations it is 1.8 mm / min. Compared with the corresponding analogues, the water permeability rate for 6 hours of observations decreases in 1.2 - 2.1 times. The ratio of the maximum values of water permeability to the minimum ones increases to 2.2 - 2.5. The variation of the absorption rate at all observation intervals was established, but the greatest decrease in the absorption rate is characteristic in the first hour of observation. The main reason for the deterioration of
water permeability of arable black soils can be explained by unfavorable changes in the structural-aggregate composition, density of addition that leads to the restructuring of the pore space. The use of heavy agricultural equipment, which has a compaction effect on the soils is also important. The water permeability of the soil at the washing site during the first hour of observation is more than two times less than on virgin black soil and 1.3 mm / min. Less than arable land in the irrigated area, the water permeability is low indicating that the soil is saturated with moisture. Also here the soil is compacted due to the destructive effect of irrigation water on the soil structure. Table 5 presents the differences in water permeability in different areas of the economic use.

Table 5. Permeability of typical black soil, mm / hour.

| Plot              | 1   | 2   | 3   | 4   | 5   | 6   | Average |
|-------------------|-----|-----|-----|-----|-----|-----|---------|
| virgin lands      | 315 | 270 | 231 | 210 | 201 | 186 | 235.5   |
| virgin lands      | 189 | 156 | 123 | 102 | 108 | 114 | 132     |
| post-irrigated    | 117 | 102 | 90  | 81  | 75  | 69  | 89      |
| irrigated         | 51  | 48  | 45  | 39  | 30  | 18  | 38.5    |

The involvement of black soils in irrigated agriculture has a double meaning in terms of changes in water i.e., physical properties. In studies where irrigation rates were 300 m³ / ha, no any significant changes in the rate of absorption were observed in comparison to the developed analogues. Irrigation with the issuance of large irrigation rates led to a change in the permeability of black soil; the rate of absorption in the first hour of observation decreased in 1.5–1.7 times.

3. Conclusion

Thus, having studied the particle size distribution and some of the agrophysical properties of typical black soils, it can be said that such important features as the grain size distribution, the density of addition, total porosity, and water permeability depend on the nature of the soil use. Over the entire range of the studied agrophysical properties of soils, arable black soils are inferior to virgin lands analogues located in similar landscape conditions. Post-irrigative soils transformed into sets aside are inferior in their agrophysical properties to virgin lands analog, but surpass arable soils in some indicators. The range of unfavorable properties of black soils acquired as a result of irrigation is rather wide and manifests itself at almost all levels of their structural organization. It should be noted that irrigation with ecologically safe irrigation norms of 300 m³/ha does not impair the physical properties of the soil, in contrast to heavy irrigation norms, which determine the unidirectional and noticeable expression of the main indicators in the direction of their deterioration.

References

[1] Akhtyrtsev B P and Lepilin I A 2011 Water-physical properties of typical black soil of the Central Russian Up land under conditions of intensive use Pochvovedenie 4 444–54
[2] Badmaeva S E and Merkusheva M G 2014 Scientific basis for the rational use of irrigated agricultural landscapes of Eastern Siberia (Krasnoyarsk) p 412
[3] Vadyunina A F and Korchagin Z A 1998 Methods for the study of soil physical properties (Moscow: Agropromizdat) p 415
[4] Vasiliev S M and Domashenko Yu E 2016 Retrospective analysis of changes in soil-meliorative conditions of irrigated soils in the south of the Rostov region News of the Nizhnevolzhsky agrouniversity complex: science and higher professional education 3(43) 17–24
[5] Vasilchenko N I and Yumankulov R V 2016 The influence of irrigation on the physicochemical properties of the black soil of typical Northern Kazakhstan Vestn. KrasGAU 5 3–9
[6] Vukolov N G and Shuravilin A V 2008 Soil transformation with long-term irrigation in the conditions of the south of Western Siberia Plodorodie 6 34–5
[7] Gorbunova N S, Kulikova E V and Shcheglov D I 2017 Chernozems of Central Russia: genesis,
evolution and problems of rational use (Voronezh: Scientific book) p 452–6
[8] Kachynskyi N A 1970 Soil physics (Moscow: Vissh. shkola) p 358
[9] Kireycheva L V 2017 Approaches to justify the placement of agricultural land reclamation Melioratsiya I Vodnoe Khozyaistvo 4 11–5
[10] Medvedev V V and Laktionova T N 2012 Analysis of the experience of European countries in the behavior of soil monitoring Soil Science 1 106–14
[11] Olgarenko I V 2010 Ecological monitoring of reclamation systems Melioratsiya I Vodnoe Khozyaistvo 4 45–7
[12] Pyagay E T 2013 Monitoring and forecast of changes in the ecological state of irrigated black soil The current state of black soil: Proceedings of the scientific conf pp 243–5
[13] Sheina E V and Karpachevsky L O 2007 Theories and methods of soil physics (Moscow: Grief and K) p 616
[14] Shchedrin V N 2018 Melioration in Russia: problems and prospects Melioratsiya I Vodnoe Khozyaistvo 6 30–6