

# Changes in the Magnetic Susceptibility of Kuban Soils Depending on Soil Formation Conditions

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**Abstract** — The article deals with changes in the magnetic properties of different agricultural soils depending on the conditions of soil formation. The Maryano-Chebourgol irrigation massif in the Krasnoarmeysky district of the Krasnodar Territory and the stationary trial field of the Department of Agricultural Chemistry of the Kuban State Agrarian University have become research sites. The objects of study are gleic chernozem and calcic chernic gleysol soils, grey-luvic chernozems of the Western Ciscaucasia. We measured the magnetic susceptibility in each soil pedogenic horizon. In our studies, we used the KM-7 sensor made in the Czech Republic, applied it to the wall of the soil profile horizon and recorded readings. It was revealed that an increase in the degree of hydromorphism reduces the magnetic susceptibility of soils. The most magnetized is the grey-luvic chernozem profile, it is  $1,045 \times 10^{-3}$  SI units in the arable horizon. In soils influenced by hydromorphic soil formation, the values of magnetic susceptibility are 3.0–3.5 times lower under conditions of rainfed and fallow lands, and 6.0–12.0 times lower in soils of rice agroecosystems.

**Keywords:** rice agrolandscapes grey-luvic chernozem magnetic susceptibility magnetic profile moving iron

## I. INTRODUCTION

All soil components have a certain magnetic activity. One of its characteristics is magnetic susceptibility which reflects the formation of strongly magnetic iron minerals in well-structured and aerated soil and can serve as an additional criterion characterizing its air-water and structural properties [1]. Iron minerals determining the magnetic susceptibility of soils are oxides and hydroxides that are crystallized to different degrees and differ in the types of crystal lattices [2]. Automorphic soils with good aeration and the prevalence of oxidizing conditions over reducing iron compounds contribute to the accumulation of oxides and hydroxides of trivalent iron. In hydromorphic soils with a stable regime of overmoistening, divalent iron compounds prevail [3]. The magnitude of the magnetic susceptibility increases with increasing intensity of the soddy process and the accumulation of humic acids, soil clayization. A decrease in its values depends on the processes of podzolization, gleization, and solodization, low pH values, fulvate composition of humus as well as the development of planar

water erosion and the presence of free carbonates in the soil [1, 4].

The magnitude of its magnetic susceptibility depends on the content of iron-containing minerals in soils [1, 5–7]. Iron-containing oxide and hydroxide minerals such as hematite  $\text{Fe}_2\text{O}_3$ , goethite  $\alpha\text{-FeOOH}$ , lepidocrocite  $\gamma\text{-FeOOH}$ , and ferroxygite  $\text{Fe}_3(\text{OH})_8$  predominate in rice field soils [8]. Their formation follows from the dehydration of amorphous hydrated compounds represented mainly by high molecular weight gels and directly from the destruction of ferrous minerals [9]. Under reducing conditions, goethite and ferroxygite prevail in the soil and pass into lepidocrocite during aeration, [10]. Under the conditions of rice sowing, the process of weathering of minerals proceeds much faster than in rainfed conditions. It leads to the accumulation of secondary minerals such as limonite and others serving as the main source of ferrous iron in flooded soil. A large amount of active iron hydroxide prone to reduction and reoxidation confirms this [11]. Moreover, ferruginous minerals in the soil, hematite, lepidocrocite, goethite can under certain conditions go into strongly magnetic compounds, such as maghemite or magnetite [12].

The goal of the work is to study the magnetic profiles of Kuban soils depending on soil formation conditions.

## II. MATERIALS AND METHODS (THE MODEL)

The Maryano-Chebourgol irrigation massif in the Krasnoarmeysky district of the Krasnodar Territory and the stationary trial field of the Department of Agricultural Chemistry of the Kuban State Agrarian University named after I.T. Trubilin have become research sites. The objects of study are gleic chernozem and calcic chernic gleysol soils, grey-luvic chernozems [13].

Profile-morphological studies were carried out according to the guidelines [14, 15].

The section on grey-luvic chernozem was made under automorphic conditions in a stationary field experiment of the Department of Agrochemistry of the Kuban State Agrarian University. According to geomorphological zoning of the plain and foothill steppe of the Krasnodar territory, the territory of the experimental field is in the Kuban delta floodplain region of the Prikubanskaya plain of the Western

Ciscaucasia. Morphological description of the soil (GPS 45° 3'50.74", N and 38° 51'19.61", E):

AA (0-25/25 cm) soil layer is fresh, dark grey, clayey, lumpy and grainy, compacted, with wormholes, root residues, gradual transition.

A (25-62/37 cm) soil layer is fresh, dark grey, clayey, lumpy, compacted, with wormholes, root residues, gradual transition.

AB<sub>1</sub> (62-109/47 cm) soil layer is fresh, dark grey with a brownish tint, clay, lumpy, medium compacted, with wormholes, root residues, gradual transition.

AB<sub>2</sub> (109-148/39 cm) soil layer is fresh, dark grey with a brown tint, clayey, lumpy, medium compacted, with wormholes, sometimes separate roots, gradual transition.

B (148-177/29 cm) soil layer is fresh, brown with dark streaks of humus, clay, with poorly expressed soil structure, medium compacted, does not boil from 10% HCl, the transition is gradual.

C (more than 177 cm) soil layer is fresh, brownish with a yellowish tint, heavy loamy, medium compacted, structureless, carbonates in the form of a white-eye, boils from 10% HCl.

Soil sections on gleic chernozem and calcic chernic gleysol soils were made within the rice irrigation system functioning since 1937 in the Krasnoarmeysky district of the Krasnodar Territory [16, 17]. Sections in gleic chernozem soil were also made in areas not used in rice crop rotation: fallow lands located on the rice irrigation system and rainfed lands located outside it.

According to geomorphological zoning, the territory of the Krasnoarmeysky district of the Krasnodar Territory is part of the Kuban delta-floodplain region and belongs to the Priazovo-Predkavkazskaya soil province of the steppe zone of ordinary and southern chernozems, the soil district of the lower Kuban river with the spread of meadow-steppe and gleic soil types.

Morphological description of the gleic chernozem soil of the rice irrigation system (GPS 45°01'25.43", N; 38°01'51.15", E) [16]:

AA (0-20/20 cm) soil layer is dry, dark grey with a bluish tinge, lumpy and grainy, with thin cracks, compacted, loamy, with streaks of rust, MnO emission in the form of black dots, ocherous strands, plant residues, wormholes, gradual transition.

A (20-59/59 cm) soil layer is dry, dark grey with a bluish tinge, clumpy and lumpy, with thin cracks, compacted, clayey, with Fe<sub>2</sub>O<sub>3</sub> manifestations in the form of rust and MnO in the form of black dots, wormholes, does not boil from 10% HCl, the transition is gradual.

AB (59-98/39 cm) soil layer is dry, dark grey with a brownish tinge, lumpy, with thin cracks, compacted, clayey, with clay streaks, rusty spots in the bottom, boils from acid from 60 cm, with the noticeable transition in colour.

B (98-134/36 cm) soil layer is moist, brown, heterogeneously coloured with streaks of humus, structureless, with thin cracks, compacted, clayey, with rusty greases, small white eyes and cranes, boil from 10% HCl, with the noticeable transition.

C (134-186/52 cm) soil layer is wet, light brown with streaks of humus, structureless, compacted, clayey, with ocher spots, white-eye, boils from 10% HCl.

Morphological description of calcic chernic gleysol soil of rice irrigation system (GPS 45° 12'31.87", N; 38° 22'7.12", E) [17]:

AA (0-18/18 cm) soil layer is dry, black grey with a bluish tint, coarse in the layer of 0-10 cm, lumpy in the layer of 10-18 cm, compacted, clayey, with rusty and buffy veins along to the structural parts of the soil, root residues, noticeable and gradual transition.

A (18-49/31 cm) soil layer is dry, dark grey with a brownish and bluish tint, lumpy, highly compacted, clayey, greasy to the touch, sticky, with smudged humus, streaks of rust, sesquioxide, noticeable and gradual in colour transition.

AB (49-102/53 cm) soil layer is dry, brownish and bluish, lumpy, clayey, greasy to the touch, boggy, sticky, compacted, chinked, with streaks of humus, small cranes and white eyes, continuous boiling from 10% HCl from 90 cm, the transition is noticeable and gradual.

B (102-149/47 cm) soil layer is moist, bluish and light brown with streaks of humus, structureless, clayey, highly compacted, chinked, with small cranes and a white-eye, boil strongly from 10% HCl, the transition is gradual.

C (more 149 cm) soil layer is wet, light brown, structureless, compacted, boggy, clayey, with carbonates, boils strongly from 10% HCl.

Morphological description of gleic chernozem soil of fallow land (GPS 45° 14'0.63", N; 38° 19'36.28", E) [17]:

Amax (0-5/5 cm) soil layer is dry, black grey, finely lumpy, heavy loamy, with semi-decomposed plant residues, weakly compacted, with wormholes, gradual transition.

A (5-30/25 cm) soil layer is dry, dark grey, lumpy, heavy loamy, compacted, with reed rhizomes and coal-black inclusions of sulfides, do not boil from 10% HCl, the transition is gradual.

AB<sub>1</sub> (30-51/21 cm) soil layer is dry, dark grey with a brownish tint, vaguely lumpy, compacted, heavy loamy, with sulfide compounds and under-oxidized products along dead and living rhizomes of the reed, boil from 10% HCl from 50 cm, the transition is gradual.

AB<sub>2</sub> (51-71/20 cm) soil layer is dry, dark grey with a brown and bluish-olive tint, structureless, heavy loamy, compacted, with dirty yellow clay spots, small cranes, sulfide coating around reed rhizomes, maximum reed rhizomes in the layer 30-71 cm, boil from HCl, with a gradual transition.

B (71-92/21 cm) soil layer is moist, light brown, structureless, compacted, loamy, with carbonate dense nodules, gradual transition, boils from 10% HCl.

C (more 92 cm) soil layer is wet, dirty yellow, structureless, compacted, loamy, with carbonate nodules, less common reed roots, boils from 10% HCl.

Morphological description of gleic chernozem soil of rainfed land (GPS 45° 12'53.79", N; 38° 18'59.04", E):

AA (0-20/20 cm) soil layer is fresh, dark grey, lumpy and grainy, compacted, loamy, with plant residues, wormholes, white-eyed, slightly boils from acid, with a gradual transition.

A (20-45/25 cm) soil layer is fresh, dark grey, lumpy and grainy, compacted, loamy, with white-eyed, plant roots, wormholes, boils from acid, the transition is gradual.

AB (45-75/30 cm) soil layer is fresh, grey, lumpy, compacted, loamy, with the abundance of white-eyes and cranes, boils from acid, the transition is noticeable in colour and granulometric composition.

B (75-109/34 cm) soil layer is fresh, brown with streaks of humus, with weakly expressed structure, compacted, loamy, with the abundance of carbonates, boils from acid, the transition is noticeable in colour.

C (109-150/41 cm) soil layer is fresh, brown with streaks of humus, structureless, heavy loam, with the abundance of carbonates, boils from acid.

We measured the magnetic susceptibility in each soil pedogenic horizon. We applied the instrument sensor to the wall of the profile horizon and recorded readings.  $\chi \times 10^{-3}$  values are expressed in SI units. The method does not require chemical or physical destruction of the soil sample.

In the selected soil samples, we determined the total humus content, the group composition of humus, divalent and trivalent mobile iron in a 0.1 N solution of  $H_2SO_4$ . Density of soil structure was determined in undisturbed soil samples. We calculated the total soil porosity on the density of soil structure and solid phase [18, 19].

### III. RESULTS AND DISCUSSION

Each type of soil has its specific magnetic profile, that is patterns of change in magnetic susceptibility along genetic horizons. Hydromorphic soils have significantly lower values than automorphic soils [1]. In grey-luvic chernozem, we recorded high values ranging from 1.045 in the arable horizon to  $0.797 \times 10^{-3}$  SI units in the pedogenic bed. The soil has the accumulative nature of the magnetic profile: with depth, the values of magnetic susceptibility gradually decrease. The aerated top layer has strongly magnetic minerals of iron, therefore, the arable horizon has the greatest magnetization (Figure 1).

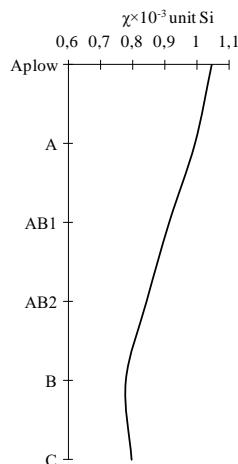


Fig. 1. Change in magnetic susceptibility along the grey-luvic chernozem profile

The content of mobile iron ( $FeO + Fe_2O_3$ ) in the soil of leached chernozem is 50.57 mg / 100 g. Ferrous oxide ( $FeO$ ) accounts for 3%, ferric oxide ( $Fe_2O_3$ ) is 97% of their total. According to the soil profile, the  $FeO$  content decreases from 1.56 mg in the arable horizon to 1.12 mg / 100 g in horizon C; and the amount of  $Fe_2O_3$  increases from 49.01 mg to 69.77 mg / 100 g. The density of soil structure is 1.30 g /  $cm^3$ , a total porosity is 52.00%, a humus content is 3.20%, a medium reaction is 6.50 units, a ratio of  $HAC$  to  $FAC$  is 2.49.

In soils of hydromorphic soil formation, the magnetic susceptibility decreases: in gleic chernozem soils under rainfed crops it is  $0.300 \times 10^{-3}$  SI units, in the fallow land it is up to  $0.178 \times 10^{-3}$  SI units, and in gleic chernozem and calcic chernic gleysol rice agroecosystem it is up to  $0.085-0.163 \times 10^{-3}$  SI units compared with grey-luvic chernozem. Moreover, calcic chernic gleysol soil has more pronounced anaerobic processes and lower values of magnetic susceptibility than in gleic chernozem soil (0.085-0.100 versus  $0.119-0.163 \times 10^{-3}$  SI units). Low values indicate a low content of crystallized strongly magnetic iron minerals in the soils[1].

The amount of mobile iron in the soils of rice agroecosystem is 3.5-6.0 times higher than in grey-luvic chernozem. Anaerobic processes are more intense in calcic chernic gleysol soil, its proportion of  $Fe_2O_3$  is 74.7-90.7%, and the proportion of  $FeO$  is 9.3-25.3% of the total  $FeO + Fe_2O_3$  in an amount of 209.65-273, 29 mg / 100 g. Divalent iron migrates along to the soil profile and accumulates in the underlying horizons AB or B.

In gleic chernozem soil, ferric oxides are predominant, their share in the arable horizon reaches 92.82-96.61%, and ferrous iron accounts for 3.39-7.18% of their total varying in the range of 173.1 -385.2 mg / 100 g. Down the profile, the  $FeO$  content decreases.

The soils of rice agroecosystem have different physical and chemical properties. The calcic chernic gleysol soil has a rather high density of arable horizons and low porosity, 1.34-1.46 g /  $cm^3$  and 45.1-49.8%, respectively. The gleic chernozem soil has a more favourable physical condition, it is 1.28-1.35 g /  $cm^3$  and 50.0-52.1%, respectively. The humus content in the soils is 3.05-3.67%. Humus type of gleic chernozem soil is humate or fulvate-humate, its ratio of  $HAC$  to  $FAC$  is 1.62-2.12, calcic chernic gleysol soil is humate-fulvate or fulvate-humate, its ratio of  $HAC$  to  $FAC$  is 1.00-1.22.

Magnetic profiles of rice field soils are differentiated by magnetic susceptibility values. They show a decrease in arable values and an increase in horizon A, it depends on the removal and accumulation of silt particles as a result of eluvial and gley processes. The latter has a high concentration dispersed ferromagnetic minerals containing iron, nickel, cobalt, titanium, organometallic and other compounds: hematite, maghemite, limonite, lepidocrocite, goethite [20]. In the underlying horizons containing 5.5-8.0%  $CaCO_3$  carbonates, the values of magnetic susceptibility decrease and slightly change with the profile depth (Figure 2). The reason for the latter is the diamagnetic nature of the carbonate alluvial underlying bed [1].

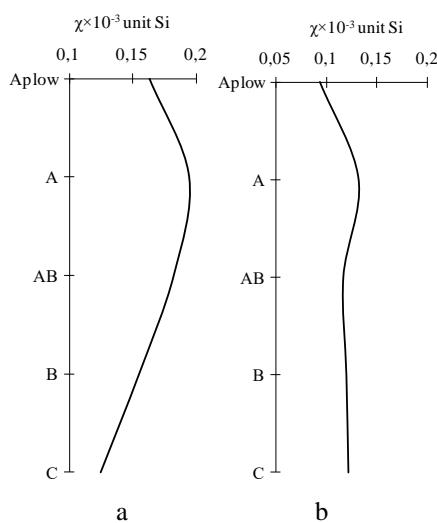


Fig. 2. Change in magnetic susceptibility along to the profile of gleiy chernozem (a) and calcic chernic gleysol soils (b)

As a result of periodic flooding of the rice field soils for 4-5 months and their subsequent drying out due to the specifics of rice cultivation, the magnetic susceptibility in the arable horizon is 2.0-3.0 times less than in the rainfed land.

In the gleiy chernozem soil used for growing rainfed crops, the humus content increases by 0.20-0.23%, humic acids accumulate when the ratio of HAC: to FAC is 2,80. The soil has a looser structure and high porosity,  $1.28 \text{ g / cm}^3$  and 52.2%, respectively.

The magnetic profile of the gleiy chernozem rainfed soil has a gradual decrease in the magnetic susceptibility from  $0.300 \times 10^{-3}$  in the arable horizon to  $0.165 \times 10^{-3}$  SI units in horizon C (Figure 3). The carbonate content in the soil affected the content of mobile iron not exceeding 13.26 mg / 100 g in the arable horizon which is much less than under rice sowing. Horizons B and C have not mobile forms of iron since carbonates exert a coagulating effect on free iron ions.

Fallow land located on gleiy chernozem soil of a rice irrigation system and not involved in rice sowing has conditions of temporary waterlogging due to the close soil-groundwater during the rice-growing season that favour the development of anaerobic processes indicated by the content of divalent iron in horizon AB<sub>2</sub> up to 49.8% of the total FeO + Fe<sub>2</sub>O<sub>3</sub>. Such soil formation conditions influenced the formation of the magnetic profile; in its lower horizons, the magnetic susceptibility values are less ( $0.168-0.186 \times 10^{-3}$  SI units) than in the humified top layer of A<sub>max</sub> + AB<sub>1</sub> ( $0.178-0.222 \times 10^{-3}$  SI units) (Figure 3).

In contrast to the soils of rice agroecosystem, the fallow land has a loose structure of the A<sub>max</sub> horizon of  $1.25 \text{ g / cm}^3$ , a high porosity of 53.00%, a high humus content of 6.01%, and an expanded ratio of HAC To FAC of 3,51. But already in the humus-accumulative horizon A, the density increases to  $1.41 \text{ g / cm}^3$ , the porosity decreases to 47.80%, the humus content is to 3.41%, and the HAC to FAC ratio narrows to 2,01.

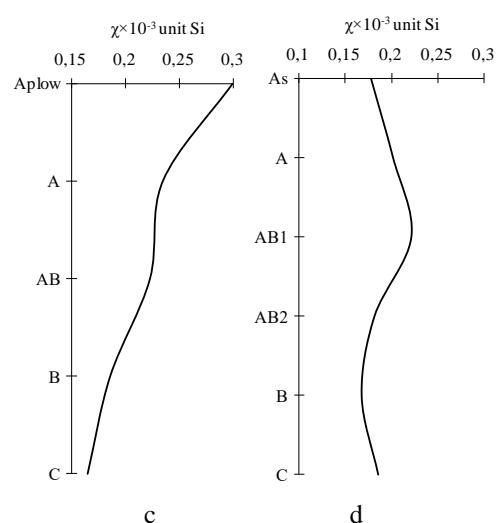


Fig. 3. Change in magnetic susceptibility along to the profile of gleiy chernozem soil of rainfed (c) and fallow (d) lands

#### IV. CONCLUSION

The soil formation conditions affect the formation of the magnetic profile of various agricultural soils. An increase in the degree of hydromorphism reduces the magnetic susceptibility of soils. The profile of grey-luvic chernozem of the Western Ciscaucasia has the greatest magnetization. Soils influenced by hydromorphic soil formation have indicators of magnetic susceptibility reduced by 3.0-3.5 times under the conditions of rainfed and fallows land, and 6.0-12.0 times in rice agroecosystem.

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