

# Origin of the gypsum-bearing horizon of Calcic Chernozems in the South of Russia

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## ABSTRACT

The aim of the study was to investigate an effect of rainfall on formation of a subsoil horizon of readily soluble salts and gypsum in Calcic Chernozem (Loamic). Mathematical and statistical methods were used to calculate the wetted depth of the soil profile under an assumption that the soil receives on its surface a one-time rainfall with volume equal to the annual precipitation. We used data for the period from 1948 to 1980 on the average long-term wetted depth of the profile of Chernozems that formed on the territory of the northern part of Cis-Azov region, a vast area within the Rostov region, Russia. A comparative analysis of actual long-term and estimated wetted depths of Calcic Chernozems was performed. The calculated wetted depth was 192 cm. In reality in the considered area, up to 71% of the water received on the soil surface penetrates to the depths from 80 to 159 cm. This indicates that the horizon of readily soluble salts and gypsum located at the depth of over 220 cm is a relic. The gypsum formation cannot be associated with the level of the current groundwater table.

**Key words :** Chernozems, Calcic chernozems, Gypsum, Wetted depth, Precipitation

## Introduction

Gypsum-bearing soils are typical for arid areas, but they are also found in the steppe, forest-steppe, and taiga. The water regimes of these soils differ. In automorphic soils, gypsum neoformations (or concentrations) can accumulate as a result of soil formation processes at the non-leaching water regime or may be inherited from soil-forming rock as residuals due to the flushing water regime. In semi-hydromorphic and hydromorphic soils, groundwater is often a source of gypsum at the exudational water regime. In the forest-steppe, the area of the surface loess-like deposits, similar conditions are often found in river valleys (Spiridonova, 2007). The most characteristic forms of gypsum neoplasms are aggregates of large crystals ("gypsum roses", "dove-tail"). The columnar gypsum is also found in soils -

a form of residual gypsum with a predominance of loosely located elongated fibrous crystals, but this form is characteristic of waterlogged soils (Bezuglova and Nazarenko, 1998). However, in any case, gypsum neoplasms are of great diagnostic value, since they contain information on the genesis of soils.

It is a challenging task to reconstruct the genesis of the gypsum-bearing horizon under condition of a historically contingent decrease in the base level of erosion and the groundwater table or climate change. However, there are modern observations (Jizzakh, Uzbekistan) indicate that a decrease in groundwater table is accompanied by a decrease in gypsum content due to the disappearance of finely dispersed gypsum crystals from soil profiles (Golovanov and Yamnova, 2013). Moreover, a rather short period of time (20 years) is needed for a

decrease in the groundwater table by only one meter.

Moghiseh and Heidari (2012) investigated a gypsum horizon, which was presumably formed during several periods: the upper part was formed under modern arid conditions, and the lower part was formed under more humid conditions. It was concluded based on the physicochemical, macro- and micro-morphological properties of gypsum horizons. The mineralogical and morphological features of salts and gypsum, their distribution in the soil profile, as well as their association to certain components of the microstructure are indicators of modern and relict soil processes. Based on these indicators, three morphotypes of gypsum-bearing horizons are distinguished: incrustational, nodular, and powdery (Yamnova and Golovanov, 2010; Yamnova, 2016).

Topography and the depth of saline and alkaline groundwater table define the differences in morphological, physical, chemical, and mineralogical characteristics of soil (Abtahi, 1977). Fazeli *et al* (2017) also came to the similar conclusion: gypsum-containing groundwater is the main source of gypsum in the soils. Ghergherechi *et al.* (2010) showed the dependence of the morphology of gypsum crystal on the process of its formation. There are many similar studies, where it is claimed that gypsum is formed under the influence of alkaline groundwater (Dregne, 1976; Stoops and Ilaivi, 1981; Verba and Yamnova, 1997). The gypsum formation in soils is a more global process. For example, Gerasimov (1937) hypothesized that the ancient gypsum crusts formed under geochemical condition of super-aqual landscape during the period of flooding. Super-aqual elementary landscapes are distinguished by the close occurrence of groundwater, which becomes a source of gypsum and other salts.

There is not a gypsum-bearing horizon in profile of Calcic Chernozems, soils that formed in the steppe zone in the northern part of Cis-Azov area; therefore, these soils are not gypsum-bearing. The characteristic morphological features of this soil are dark gray, turning into dark brown and brown down the profile. The depth of the incision is 145 cm. The effervescence is weak from 25 cm, from 36 cm - strong. Carbonate mycelium from 34 cm. White-eye - from 85 cm. Soil - Calcic Chernozem.

However, the gypsum-bearing horizon lies outside the soil profile in the soil-forming rock. The literature review showed that the nature of this hori-

zon in these soils is not well understood and there is still no consensus on the genesis of the horizon of readily soluble salts and gypsum in Calcic Chernozems. A detailed description of the structure, chemical composition, and order of occurrence of salts and gypsum in soils has not been published yet. Precipitation and topographic settings strongly affect the amount and location of gypsum in the soil profile (Watson, 1985). Therefore, researchers often assume that the salt and gypsum horizon is formed due to the leaching of these salts outside the soil profile, i.e. into the parent rock. Most researchers are of the opinion that the gypsum horizon was formed due to the washing out of salts, including gypsum, from the upper part of the soil profile with downward flow of soil solution. This opinion was formed, probably, due to the fact that readily soluble salts in these soils most often do not form an independent horizon but accompany the horizon of gypsum accumulations. Afanasyeva (1974) directly points out that in Calcic and Haplic Chernozems all salts, the solubility of which does not depend on the partial pressure of carbon dioxide in the soil air, sink to the lower limit of the spring soil wetting in the wettest years. In other words, they fix the lower boundary of the steppe chernozems profile (Afanasyeva, 1974). This opinion has become widespread (Bezuglova and Khyrkhyrova, 2008; Val'kov *et al.*, 2008; Kazeev *et al.*, 2010), although a detailed study in the specific conditions of the Rostov region (Russia) has not been carried out.

At the same time, it is shown that in the Calcic Chernozems of the Krasnodar region (Russia) the long-term anomalous conditions (relatively cold winters, hot and dry summers, moisture coefficient  $\leq 0.7$ ) increased the role of the percolative constituent in the water regime of the soils and change the distribution pattern of carbonates and other diagnostic features (Bazykina *et al.*, 2015). Krasnodar region is characterized by more optimal moisture conditions due to the proximity of the sea and the shadow effect of the Caucasus Mountains. Nevertheless, such investigations prompted us to conduct a more detailed study of the depth of the soil layer wetting. Moreover, a detailed description of the structure, chemical composition and order of occurrence of the salt horizons has not yet been published. After detailed research, it was concluded that this assumption contradicts the water regime of these soils.

The aim of this work is to study the effect of pre-

precipitation on the formation of the horizon of readily soluble salts and gypsum in Calcic Chernozems.

## Objects and Methods

### The Object of Research

According to modern concepts of the genesis of Chernozems, the accumulation horizon of readily soluble salts and gypsum is part of the soil profile of Chernozem soils of steppe landscapes (Russia). Relief-forming rocks here are Neogene and Quaternary deposits with a thickness of 30-40 meters and more. The soil-forming rocks are represented by loess-like clays and loams (Bezuglova and Khyrkhyrova, 2008)

In this paper, we exclusively consider the subtype of Calcic Chernozems that was first described by L.I. Prasolov in 1906 as Cis-Azov chernozems. These soils are spread across a vast area, which includes 11 administrative districts (Fig. 1) in the south-west of the Rostov region, Russia, in the southern part of the East European Plain.

Calcic Chernozems formed in the steppe zone at the boundary of two climatic subzones - the moderately warm subzone of Eastern Europe and the warm subzone of Southern Europe. The climate is semi-arid. The average annual precipitation is 453 mm. The sum of temperatures for a period with temperature above 10 °C is 3000—3400 °C, the duration of the frost-free period is 165-190 days.

Calcic Chernozems are formed on interfluvial

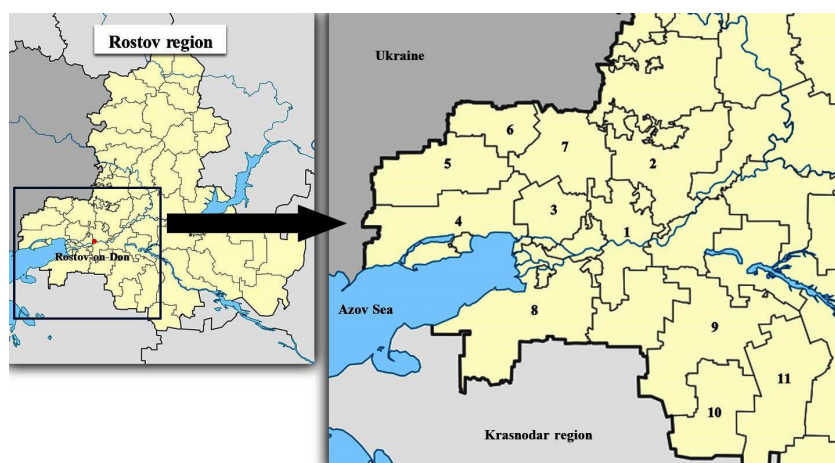
plateaus and in the upper parts of very gentle slopes. The total area is 434,000ha.

The thickness of humus horizons of Calcic Chernozems (of thick genera) ranges from 87 to 91 cm. Effervescence with 10% HCl is observed from the surface, a carbonate concentration is found from the depth of 60-70 cm, and carbonate nodular (white-eye) is examined from the depth of 100-110 cm. Generally, the horizon of readily soluble salts and gypsum is located at a depth of more than 300 cm, but it also can be determined at a depth of 220-250 cm (Bezuglova and Khyrkhyrova, 2008).

### Methodology

In the South of the Rostov region, 12 full-profile sections were laid on the watershed areas represented by Calcic Chernozems. The annual wetted depth of profile of Calcic Chernozems was determined and the frequency of occurrence of the most typical wetted depth for 33 years was calculated based on the data of long-term meteorological observations, including soil moisture, its wetted depth in spring, that were collected by a network of 76 meteorological observing station in the Rostov region, Russia to the unified methodology of the USSR Hydrometeorological Center (Svisyuk, 2002).

Due to insufficient information on the genesis of the horizon of readily soluble salts and gypsum of the studied soils, a methodology that simulated ideal condition was developed. It included calculations of the wetted depth of one-time infiltration of



**Fig. 1.** Location of the research area (coordinates of observation sites): First agroclimatic subarea: 1 – 47.236620; 39.656863, 2 – 47.30279; 40.39159, 3 – 47.162836; 39.275644, 4 – 47.183960; 38.554820, 5 – 47.343459; 38.532177, 6 – 47.464914; 38.515796, 7 – 47.363305; 39.392319, 8 – 47.02335; 39.144125; The second agroclimatic subarea: 9 – 46.906540; 40.446450, 10 – 46.30458; 40.345538, 11 – 46.335393; 41.21078.

water volume into the soil equal to the maximum annual rainfall in the studied region. The wetted depth was calculated without consideration of percolation, transpiration, soil evaporation, surface and subsoil runoff. Formulated differently, any water loss from the soil was excluded in order to calculate the maximum possible wetted depth with the current rainfall in the region.

A comparative analysis of the actual multiannual wetted depth of Calcic Chernozems and the estimated depth was performed with the example of 11 administrative districts. A water storage in the soil profile of Calcic Chernozems was also calculated using the hydrological constants and the given thickness of the profile. The calculation methodology and some of the detailed results were published by us earlier (Morozov *et al.*, 2017). The chemical composition of the artesian water of the Rostov region was carried out in accordance with GOST R 57554 - 2017, GOST 31957-2012 (State Standard). The content of carbonates was determined by the gas-volumetric method (according to the amount of carbonate  $\text{CO}_2$  released during their destruction with hydrochloric acid). The organic matter of humic acids (SOM) were determined on a TOC-L CPN Shimadzu carbon analyzer with the solid sample combustion unit SSM-5000A. The particle size distribution was determined by the sedimentation method. Soil moisture was determined by the gravimetric method, soil density - by the cutting ring method (GOST 5180-84). All other parameters (MHC – maximum hydroscopic capacity; MWHC – minimum water-holding capacity; MAWHC – maximum adsorption water-holding capacity of soils) were determined by calculation.

## Results and Discussion

The average long-term maximum rainfall on the

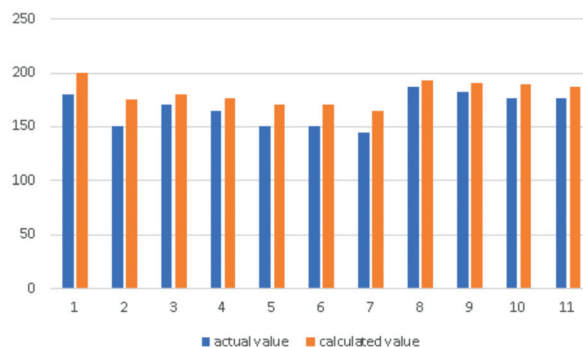
**Table 1.** Calculation of the wetted depths of Calcic Chernozems

| Horizon    | Thickness, cm | Soil density, $\text{Q, g cm}^{-3}$ | Porosity, % | MHC, %* | MWHC, %* | Reserved MCH, $\text{m}^3 \text{ha}^{-1}$ | Reserved MWHC, $\text{m}^3 \text{ha}^{-1}$ | Reserved MAWHC, $\text{m}^3 \text{ha}^{-1}$ * | Reserved MWHC – reserved MAWHC, $\text{m}^3 \text{ha}^{-1}$ * |
|------------|---------------|-------------------------------------|-------------|---------|----------|-------------------------------------------|--------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|
| Àplough    | 25            | 1.00                                | 56.1        | 8.1     | 45.5     | 202.5                                     | 1137.5                                     | 303.8                                         | 833.8                                                         |
| Àsubplough | 20            | 1.20                                | 51.3        | 8.6     | 41.8     | 206.4                                     | 1003.2                                     | 309.6                                         | 693.6                                                         |
| B1         | 20            | 1.40                                | 48.5        | 8.9     | 38.4     | 249.2                                     | 1075.2                                     | 373.8                                         | 701.4                                                         |
| B2         | 16            | 1.30                                | 47.7        | 8.5     | 36.4     | 176.8                                     | 757.1                                      | 265.2                                         | 491.9                                                         |
| BC         | 14            | 1.40                                | 45.3        | 8.1     | 32.2     | 158.8                                     | 631.1                                      | 238.1                                         | 393.0                                                         |
| C1         | 55            | 1.45                                | 44.2        | 7.0     | 34.5     | 500.5                                     | 2466.8                                     | 750.8                                         | 1716.0                                                        |
| C2         | 42            | 1.45                                | 44.2        | 7.0     | 34.5     | 429.3                                     | 2116.1                                     | 644.0                                         | 1472.0                                                        |

south of the Rostov region is 650 mm. Considering the values of some physical properties of Calcic Chernozems (Sadimenko *et al.*, 1977), it is possible to determine the hypothetical depth of water infiltration assuming that moisture is supplied to the surface of dry soil at one time in an amount of 650mm. In order to do this, the maximum water holding capacity of the soil should be known. Thus, in Aksaiskii district, given a maximum wetted depth of 180 cm, the pore space of the soil profile is 585.6mm, therefore, to hold 650mm of water another 64.4mm of pore space will be required, which corresponds to 19.8 cm of soil profile thickness (Fig. 2). As a result, the estimated depth of water penetration is 200 cm for Chernozems of the Aksaiskii district.

In a similar way, we calculated the wetted depths of Calcic Chernozems with an assumption that the water volume received on the soil surface at one time is equal to the average long-term precipitation (Table 1).

Calculations show that the maximum amount of water that the profile of the studied soil (thickness



**Fig. 2.** Comparative analysis of the actual long-term and estimated wetted depths of Calcic Chernozems of the northern part of Cis-Azov area: 1, 2 ... 11 – decoding is in Fig. 1.

of 192 cm) can hold due to adsorption is  $2885 \text{ m}^3 \text{ ha}^{-1}$ . At the same time, the maximum amount of capillary moisture that this profile can accommodate is 918.7 mm.

Thus, the rainfall penetration depth is 192 cm given the field moisture content of the soil that corresponds to the MAWHC, and assuming that the soil received a one-time volume of water equal to the annual rainfall. Since the horizon of readily soluble salts and gypsum lies at a depth of 220-250 cm, it can be argued that this salt horizon is not fed by precipitation, and it is of relict origin.

Since groundwater lies at a depth of 20 to 60 meters, depending on the topography, gypsum formation cannot be associated with current groundwater, since it is known that under natural conditions the capillary rise of water does not exceed 5-6 m (200 feet) (Dobrovolsky, 1998; Keen, 2009). However, if we assume that ancient level of groundwater table was higher than the current one (Hydrogeology of the USSR, 1970), then the possible relict origin of the horizon of readily soluble salts

and gypsum can be confirmed based on the mineralogical composition of artesian (Table 2). This horizon is a relic of past eras, when the climate was much more humid, and the groundwater level was higher. As for the evolution of the landscape, the extreme moisture content was in the 3rd millennium BC. At its end - the beginning of the 2<sup>nd</sup> millennium BC humid period was replaced by a sharp aridization, which intensified the development of salinization and carbonatization of soils in the region (Pesochina, 2018).

The next step was to resolve the issue of the maximum possible one-time precipitation over the entire period of monitoring observations. Climate handbooks contain long-term data on monthly and daily maximum precipitation of two meteorological stations in the Rostov region for the observation period from 1901 to 2017 (Table 3). They indicate that monthly maximum precipitation values never reached the calculated values necessary to fill the entire pore space to the depth of easily soluble salts and gypsum.

**Table 2.** The chemical composition of the artesian water of the Rostov region (well no.10020 located on the territory of OOO Leninskoe Znamia, village Krugloe, Azovskii district, Rostov region).

| Water sampling date/<br>Sampling depth, m | Dry<br>weight,<br>$\text{g dm}^{-3}$ | Total/Eliminated<br>water<br>hardness,<br>$\text{mmol dm}^{-3}$ | Basic chemical components, $\text{mg dm}^{-3}$ |                               |                                                              |                  |                  |                                 |
|-------------------------------------------|--------------------------------------|-----------------------------------------------------------------|------------------------------------------------|-------------------------------|--------------------------------------------------------------|------------------|------------------|---------------------------------|
|                                           |                                      |                                                                 | Cl <sup>-</sup>                                | SO <sub>4</sub> <sup>2-</sup> | HCO <sub>3</sub> <sup>-</sup> /CO <sub>3</sub> <sup>2-</sup> | Ca <sup>2+</sup> | Mg <sup>2+</sup> | Na <sup>+</sup> +K <sup>+</sup> |
| Water sampling date/<br>Sampling depth, m | 2.5                                  | 19.4/6.2                                                        | 508                                            | 847                           | 399                                                          | 201              | 113              | 477                             |
|                                           | 2.6                                  | 16.2/3.1                                                        | 918                                            | 604                           | 189                                                          | 120              | 124              | 584                             |
|                                           | 2.6                                  | 22.7/3.42                                                       | 671                                            | 1140                          | 200                                                          | 191              | 160              | 532                             |

**Table 3.** Maxima and minima of precipitation in the city of Rostov-on-Don, mm (according to the Hydrometeorological Center of the Rostov region (Weather and climate, 2019)

| Month      | Norm | Monthly<br>minimum<br>(year) | Monthly<br>maximum<br>(year) | Daily<br>maximum<br>(year) |
|------------|------|------------------------------|------------------------------|----------------------------|
| January    | 57   | 4 (1911)                     | 189 (1920)                   | 38 (1980)                  |
| February   | 51   | 1 (1931)                     | 168 (2004)                   | 33 (1994)                  |
| March      | 52   | 0.7 (1903)                   | 111 (2009)                   | 36 (1981)                  |
| April      | 44   | 4 (1913)                     | 125 (1977)                   | 39 (1987)                  |
| May        | 52   | 1 (1936)                     | 187 (1916)                   | 78 (1925)                  |
| June       | 65   | 4 (1901)                     | 178 (1919)                   | 100 (1929)                 |
| July       | 50   | 0.8 (1904)                   | 186 (1927)                   | 78 (1927)                  |
| August     | 44   | 0.5 (1886)                   | 125 (2004)                   | 50 (2006)                  |
| September  | 43   | 0 (1909)                     | 169 (1996)                   | 54 (2011)                  |
| October    | 39   | 0 (1896)                     | 157 (2013)                   | 53 (2013)                  |
| November   | 50   | 2 (1926)                     | 161 (1911)                   | 39 (2006)                  |
| December   | 67   | 1 (1920)                     | 156 (1921)                   | 37 (1982)                  |
| Whole year | 614  | 288 (1949)                   | 932 (2004)                   | 100 (1929)                 |

This fact also makes it possible to cast doubt on the relationship between the horizon of readily soluble salts and gypsum with the long-term average wetted depth of the soil profile and, accordingly, with the modern formation process of chernozems and the structure of Calcic Chernozems in the northern part of Cis-Azov area. This is probably a consequence of the pedogenesis stage preceding the Chernozem formation, which is confirmed by the studies of the authors who consider the accumulation of gypsum in modern automorphic soils as a result of paleohydromorphism (Dregne, 1976; Abtahi, 1977; Verba and Yamnova, 1997; Minashina and Shishov, 2002; Yamnova *et al.*, 2007; Golovanov and Yamnova, 2013; Yamnova and Pankova, 2013).

## Conclusion

The wetted depth of Calcic Chernozems of the northern part of Cis-Azov area is 192 cm given that the field moisture is equal to the maximum molecular water-holding capacity, and assuming that the soil received a one-time volume of water equal to the annual precipitation. Since the readily soluble salts and gypsum lies at a depth of 220-250 cm, it can be argued that this salt layer is not fed by atmospheric precipitation, and it is of relict origin in Calcic Chernozems.

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