Monitoring-based investigation of Cambisols moisture regimes for areas in autonomous relief positions

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Abstract. In 2012 - 2018 water regime monitoring was carried out at two areas of Cambisols (non-gleyic and Gleyic) in autonomous relief positions (hill tops) of the Sambian hilly moraine plain (Kaliningrad region). Differences between soils in duration of the desiccation period (moisture content < lento-capillary point) and overmoistening period (moisture content > field capacity) in the 0 - 20 cm and 0 - 100 cm layers are established. Formation of zones with critical air supply (aeration porosity below 10%) has been studied.

1. Introduction

The morphology, properties and agricultural use of soils depend on the water regime. Many studies are focused on the certain aspects of the hydrological regime and on its modelling [1-10]. Meanwhile, such data are necessary when studying and comparing widespread soils, for example Cambisols [11].

On the territory of today’s Kaliningrad region, Cambisols (Brown Forest soils, Braunerde) were first identified by N. Stremme and then by J. Rossmann [12]. The main area of Cambisols distribution in the Kaliningrad region is located in the Western part of the region (the Sambian and Warmian hilly-moraine plains and hills). To date, the water regime of Cambisols has not been studied. This problem is particularly relevant for drained agricultural landscapes under the current climate change [13-14].

Aim of research: to find out the causes of differences in hydromorphism of Cambisols in autonomous positions of the relief (tops of hills) based on long-term monitoring studies in the context of agricultural landscape.

2. Objects and methods of research

The research was carried out in 2012 - 2018 on an arable field (the experimental area of "Pereleski") in the Zelenogradsk district of the Kaliningrad region within the Sambian hilly-moraine plain, South-Eastern Baltic Region. The soil cover of the field is contrasting. On the tops and slopes of the hills there are Cambisols (including Stagnic and Endogleyic Cambisols). Soil-forming rocks for Cambisols are boulder moraine and water-glacial leached sands, sandy loam, loam with layers of clays. The depressions are occupied by Gleysols formed on carbonate deposits of complex genesis (lake-glacial clays, moraine loam and sandy loam with some deluvium).

From 2012 to 2016 the soils of the experimental area were not plowed, in 2017 there was arable land with winter wheat, in 2018 these territories were used for winter rape crops.

The water regime was studied in two areas of Cambisols located in autonomous positions of the relief (tops of hills): 1) non-gleyic sandy loam Cambisols (pit 1, 54°79'65“ N, 20°38'56“ E), underlain
Soil morphology was studied in soil pits. Soil samples were taken from all horizons. Soil names are given according to WRB [9]. The moisture regime was studied by drilling 2 times a month with layer-by-layer sampling every 10 cm to a depth of 1 m. The research period was from April to November each year. The analysis of field moisture content \( \theta_h \) was made using the thermostat-gravimetric method and then converting the data to the volumetric moisture content \( \theta \). Statistical and graphical data processing was performed in Excel. Physical properties of soils were determined: particle size distribution - according to pipette method with pretreatment 4% \( \text{Na}_2\text{P}_2\text{O}_7 \) [15]; particle density (PD) - pycnometrically; soil bulk density (D) with the method of cutting rings (cylinders); total porosity (TP) and porosity of aeration - by calculations. For each layer, the soil hydrological constants have been determined: the maximum hygroscopic moisture content (MHM) and minimum water capacity (=field capacity FC) - with the method of plaster plates in the laboratory by Nikolayev [16]; the moisture of lento-capillary point (MCP) for sand and loamy sands was assumed to be 0.6FC, for loams - 0.7FC. Wilting point (WP) was calculated as 1.5 MHM. The total moisture content (maximum water capacity MWC) is approximately equal to the total porosity [15].

3. Results and discussion

According to modern data, the average annual rainfall for the studied area is 781 mm. During the study period, two years were wet (2012 and 2016), one - extremely wet (2017), one - slightly arid (2015), two were dry (2014, 2018), 2013 was the closest to the average annual values (table 1).

| Years of research | Average annual temperature, °C | Precipitation per year, mm | Precipitation April - October, mm |
|-------------------|-------------------------------|-----------------------------|----------------------------------|
| 2012              | +7.7                          | 977                         | 678                              |
| 2013              | +8.2                          | 798                         | 531                              |
| 2014              | +9.1                          | 631                         | 380                              |
| 2015              | +9.2                          | 715                         | 326                              |
| 2016              | +8.9                          | 921                         | 533                              |
| 2017              | +8.6                          | 1090                        | 660                              |
| 2018              | +8.9                          | 617                         | 382                              |

Let us consider the physical properties of soils (table 2). The values of the bulk density of the humus horizon in pit 1 are typical for soil. Plow pan is missing. The total porosity of the humus horizon is satisfactory (51%) according to the scale by N. A. Kachinsky [15]. Aeration porosity is optimal. Drilling showed that in some plots of the Cambisols area (pit 1) there were sand layers at 70 cm and below. This leads to rapid filtration of moisture in space.

The bulk density of the humus horizon of Endogleyic Cambisols (pit 2) is much higher compared to that in pit 1 and is close to the critical one for the arable layer (1.40 g/cm³). The consequence of the increased bulk density is unsatisfactory porosity in the humus horizon (46.2%). In the subsurface horizon a plow pan has developed, the density being about 1.6 g/cm³ (table 2).
Illuvial horizons and soil-forming rock are characterized by low values of total porosity and air capacity (14% in the layer of 60 - 100 cm). In these layers, the accumulation of silt is detected both due to the initial lithological discontinuity of moraine rocks, and due to the development of lessivation (cutans in the cavities of roots and in large pores).

| Horizon and depth, cm | Physical properties | Soil hydrological constants |
|----------------------|---------------------|----------------------------|
|                      | D  | PD  | TP  | MHM | WP  | MCP | FC  |
| Pit 1                |    |     |     |     |     |     |     |
| Ap 0 - 20            | 1.26 | 2.57 | 51.0 | 4.5 | 6.8 | 18.5 | 26.4  |
| A 20 - 30            | 1.28 | 2.60 | 50.8 | 3.8 | 5.2 | 17.6 | 25.2  |
| B1 30 - 55           | 1.42 | 2.64 | 46.1 | 5.7 | 8.7 | 17.3 | 24.7  |
| B2 55 - 90           | 1.57 | 2.65 | 40.8 | 5.3 | 8.3 | 18.9 | 27.0  |
| C1 90 - 130          | 1.56 | 2.66 | 41.6 | 5.6 | 8.6 | 18.3 | 26.2  |
| C1 130 - 150         | 1.56 | 2.65 | 41.6 | 5.9 | 8.9 | 18.2 | 26.0  |
| C1 150 - 170         | 1.55 | 2.66 | 41.7 | 5.7 | 8.6 | 17.0 | 24.3  |
| C1 170 - 190         | 1.57 | 2.67 | 41.2 | 5.5 | 8.4 | 12.4 | 20.7  |
| C2 190 - 210         | 1.47 | 2.68 | 45.2 | 1.3 | 2.4 | 8.9  | 14.8  |
| C2 210 - 240         | 1.48 | 2.69 | 45.0 | 1.2 | 2.0 | 7.1  | 11.8  |
| Pit 2                |    |     |     |     |     |     |     |
| Ap 0 - 20            | 1.40 | 2.60 | 46.2 | 4.1 | 6.5 | 12.8 | 21.2  |
| A 20 - 25            | 1.53 | 2.62 | 41.6 | 4.0 | 6.4 | 12.5 | 20.8  |
| B1g 25 - 47          | 1.64 | 2.66 | 38.4 | 4.4 | 7.2 | 12.5 | 20.8  |
| B2g 47 - 80          | 1.65 | 2.68 | 38.4 | 5.1 | 8.1 | 17.0 | 24.4  |
| B3g 80 - 103         | 1.67 | 2.67 | 37.5 | 5.2 | 8.5 | 18.2 | 26.0  |
| Cg 103 - 120         | 1.66 | 2.66 | 37.6 | 5.8 | 9.6 | 18.7 | 26.7  |
| Cg 120 - 150         | 1.67 | 2.67 | 37.1 | 5.5 | 9.2 | 16.1 | 23.0  |

The accumulation of silt in the lower soil horizons leads to deterioration of moisture filtration. On the other hand, the water-holding capacity of silted horizons increases. Therefore, despite the light granulometric composition of soil, the conditions for periodic accumulation of gravitational moisture over silted horizons are being formed. As shown by drilling, in the area around pit 2 there are clay layers, which complicates the lateral flow of moisture and leads to stagnation of water in the illuvial horizons of the soil. Signs of weak gleying were found in the profile at 25 cm, and at 80 cm the soil becomes strongly gleyic.

According to the reclamation plan, the soil is drained by closed drainage. The last reconstruction of the drainage network was carried out in 1975.

Processing of data on the long-term dynamics of moisture in autonomous Cambisols allows determining the quantitative indicators of hydromorphism for the arable layer of 0 - 20 cm and of the 1-m thickness (table 3). The duration of the drying period is determined by the number of days with moisture less than MCP. This period in the non-gleyic Cambisols is on average 25 days longer compared to the Gleyic Cambisols layer of 0 - 20 cm.
The overmoistening period was estimated by the number of days with soil moisture content greater than FC. This period is 17 days longer in the arable layer of Gleyic Cambisols. However, the arable horizon is a zone of high hydrological dynamism. Therefore, we have determined the quantitative characteristics of the degree of drying and overmoistening also for the 1-m layer of the Cambisols (table 4). All indicators demonstrate significant differences confirming a greater degree of hydromorphism of Gleyic Cambisols.

In the humid 2012 and 2016 drying of Gleyic Cambisols on the abandoned field was not observed. And on winter wheat crops, this indicator is close to the non-gleyic Cambisols. This indicates a strong influence of crops on the soil moisture regime. Winter wheat grown by intensive technology is characterized by high water consumption.

**Table 3.** Quantitative characteristics of the degree of hydromorphism of Cambisols in autonomous positions of the relief in hilly moraine landscapes of the Sambian plain (for the period from April to October). Layer 0 - 20 cm.

| Years of research | Indicator | Sum of days with \( \theta < \) MCP | Sum of days with \( \theta > FC \) |
|-------------------|-----------|-----------------------------------|-----------------------------------|
|                   | Pit 1     | Pit 2                             | Pit 1                             | Pit 2                             |
| 2012              | 12        | 0                                 | 74                                | 100                               |
| 2013              | 50        | 11                                | 50                                | 67                                |
| 2014              | 42        | 30                                | 58                                | 85                                |
| 2015              | 45        | 30                                | 45                                | 55                                |
| 2016              | 33\(^a\)  | 0                                 | 62                                | 75                                |
| 2017              | 27        | 30\(^a\)                          | 122                               | 145                               |
| 2018              | 100       | 30                                | 35                                | 40                                |
| Average for 2012 - 2018 | 44        | 19                                | 64                                | 81                                |

\(^a\) For layer 0 - 10 cm.

The current water regime of soils is characterized by annual wetting of the meter thickness, but the period of overmoistening from April to October in the Gleyic Cambisols soil is on average 34 days longer compared to the non-gleyic Cambisols.

In 2012 and 2017 years, the gleyic soil is in a state of overmoistening (\( \theta > FC \)) for about three months during the vegetation season.

Moisture content greater than FC in the horizon or in the soil profile does not always lead to the development of gleying. Light loam and adjacent moraine loamy sand have a fairly wide interval between FC and MWC. In the humid climate of the region under study, the soil moisture content greater than FC is a typical phenomenon. An important criterion for assessing the degree of soil hydromorphism is the number of air pores, which is calculated as the difference between the total porosity and the actual field moisture in volume percentages [15] for each sampling date. With air porosity (AP) in the profile (or horizon) below the critical level of 10%, unfavorable conditions for root growth occur, and at levels below 5%, anaerobic processes lead to the development of gleying [17].
Table 4. Quantitative characteristics of the degree of hydromorphism of Cambisols in autonomous positions of the relief in hilly moraine landscapes of the Sambian plain (for the period from April to October). Layer 0 - 100 cm.

| Years of research | Sum of days with $\theta < \text{MCP}$ | Depth of penetration drying $< \text{MCP}$ (cm) | Sum of days with $\theta > \text{FC}$ around the 1m layer |
|-------------------|---------------------------------------|-----------------------------------------------|--------------------------------------------------|
| Pit 1             | Pit 2                                 | Pit 1                                        | Pit 2                                           |
| 2012              | 45                                    | 60                                           | 5                                               |
| 2013              | 60                                    | 20                                           | 5                                               |
| 2014              | 60                                    | 60                                           | 5                                               |
| 2015              | 90                                    | 40                                           | 5                                               |
| 2016              | 30                                    | 0                                            | 5                                               |
| 2017              | 30                                    | 70                                           | 5                                               |
| 2018              | 90                                    | 42                                           | 5                                               |
| Average for 2012-2018 | 47                                  | 20                                           | 73                                              |

Moisture monitoring data allow us to estimate the duration of periods with different amounts of air-filled pores (Table 5). In non-gleyic Cambisols, AP below 10% was observed in five years out of seven at a depth of 70 - 100 cm lasting from 15 to 30 days. The layer with AP of less than 5% was discovered only in the extremely humid 2017. In layer 0 - 100 cm temporary perched water is missing.

Table 5. Air porosity (AP) in Cambisols. Layer 0 - 100 cm.

| Years of research | Sum of days with AP below 10% | Sum of days with AP below 5% | Depth (cm) of area with AP below 10% |
|-------------------|-----------------------------|-----------------------------|------------------------------------|
| Pit 1             | Pit 2                       | Pit 1                       | Pit 2                              |
| 2012              | 15                          | 165                         | 0                                  |
| 2013              | 0                           | 210                         | 0                                  |
| 2014              | 0                           | 180                         | 0                                  |
| 2015              | 15                          | 150                         | 0                                  |
| 2016              | 15                          | 210                         | 0                                  |
| 2017              | 30                          | 150                         | 15                                 |
| 2018              | 15                          | 30                          | 15                                 |
| Average for 2012-2018 | 13              | 154                         | 2                                  |

In Gleyic Cambisols, due to the low porosity of the aeration at moisture content equal to FC, even a small amount of overmoistening leads to the development of areas with insufficient air supply. This explains why in these soils and in years with low rainfall for the region, there is a deficit of air-filled pores.
The average duration of this period in the studied 7 years was about five months. In November 2016 and 2017 at a depth of 110 - 120 cm, a spatially discontinuous temporary perched water layer was formed. This explains the semi-hydromorphic nature of the soil and the development of gleying in the profile on the hill top.

4. Summary
On the moraine plains, the moisture regime of Cambisols in autonomous positions of the relief (hilltops) is controlled by the lithological features of the vertical and horizontal bedding of soil-forming rocks and the distribution of silt in the profile.

In agricultural landscapes of the Sambian plane, non gleyic Cambisols are formed on light loams underlain by sands. The presence of silty horizons in the profile and clay layers in space creates the conditions for temporary excessive moisture, additional accumulation of moisture and formation of Stagnic (Endogleyic) Cambisols.

In the course of a long-term monitoring, differences between non-gleyic and gleyic Cambisols were found in the duration of the periods of drying (moisture content < lento-capillary point) and overmoistening (moisture content > field capacity) both in the arable horizon (0 - 20 cm) and in the meter layer (0 - 100 cm).

Quantitative indicators of hydromorphism for autonomous Cambisols in the region under study have been determined for the first time. These data should be taken into account both in basic research (genesis, evolution, soil classification), and in practical applications (formation of productive moisture reserves, fertilizer efficiency, diversity of yield), as well as in remote sensing and soil mapping and introduction of precision farming systems.

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