Hydrological constants and water regime of a Calcic Chernozems in the zone of true steppe of Ukraine

O. V. Kotovych*, J. M. Recio Espejo**, V. M. Yakovenko*, A. O. Dubina*, O. G. Karas*, L. P. Travleyev

*Oles Honchar Dnipro National University, Dnipro, Ukraine
**University of Córdoba, Córdoba, Spain

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Introduction

Soil is the main natural resource owned by Ukraine. Of the total arable land area, about 60% are located in the zone of insufficient moisture, where the lack or deficit of moisture is the leading factor limiting productivity of native ecosystems and artificial agrocenoses. The modern period is characterized by dynamic changes in climate indicators, which leads to changes in soil regimes and properties. It is possible to assess the degree of transformation of the soil cover with the use of baseline soil monitoring (Medvedev, 2012). Obtaining baseline values of soil moisture is possible on surface areas not used for growing crops because they reflect the features of zonal moisture.

The moisture regime of watershed sites in this part of the steppe zone is formed under the influence of natural factors forming the regime mainly represented by precipitation and temperature indicators. Their interrelation and varied influence determine the diversity of hydrological conditions. Humidification of steppe edaphotopes forms a part of the general hydrological characteristic of the region. In the conditions of the Prisamarya Dniprovsky region, this issue was worked on at different times by L. P. Travleyev (Travleyev, 1982), Y. I. Gritsan (Gritsan, 2000), O. V. Kotovich (Kotovich, 2010).

Materials and methods

Knowledge about water-physical properties of soils is necessary to water regime monitoring and water balance calculations, and it is serve as a basis for determining soil-hydrological constants. Our study was based on the doctrine of the water regime of soils formulated by G. M. Vysotsky (Vysotsky, 1933) and afterwards detailed by O. A. Rode (Rode, 2008, 2009) and M. F. Kulik (Kulik et al., 1979).

Practical studies were conducted in the field and laboratory conditions. Soil samples were taken from soil sections and shafts with an interval of 10 cm for determination the water-physical properties of the soil. Soil samples for the moisture determination were obtained using a soil and Izmailska and Derkulinska soil augers. Soil samples were taken at the beginning and end of the growing season from a two-meter layer of soil with an interval of 10 cm in the period from 2013 to 2017. Natural humidity and soil density were determined by thermostatic-weight and weight methods in accordance with DSTU B A. 1.1-25.

In the laboratory was determined: total moisture capacity (TMC) as the maximum amount of liquid water which can be absorbed by soil with undisturbed structure; it was determined with experimental gravimetric analysis by saturation of soil samples with liquid water (Vadyunina, 1986); the minimum moisture-holding capacity (min.MHC) which is the maximum amount of water that a free-drained soil can retain; it was determined in the laboratory with gravimetric method in undisturbed soil monoliths (Vadyunina, 1986); the wilting coefficient (WC) as the value determined by multiplying the values of MGV by a factor of 1.5; the maximum hygroscopic content (max.MHC) determined by saturating of soil samples in a container with a saturated solution of potassium sulfate, where the relative vapor pressure is equal to 98% (Vadyunina, 1986); the humidity of the soil (HU) as the amount of water that a soil sample can retain in a container with a saturated solution of potassium sulfate (Vadyunina, 1986).

The characteristics of important water-physical properties and water-balance monitoring results for Calcic Chernozems located in the zone of true steppe were provided. The differences between soil-hydrological constants in carbonated loess-like loam and organogenic horizons were established. The results of water-balance monitoring showed that the moisture has uneven distribution along the soil profile, and most of the active moisture (more than 90%) was accumulated within the range of depths from 0 to 150 cm. During the entire calendar year, the soil is characterized by a lack of moisture available to plants. There are no periods free from water deficit.

Keywords: water-physical properties; soil-hydrological constants; water regime; Calcic Chernozem
the highest reserves of productive moisture in the soil, or a range of active moisture (RAM) determined as the difference between TMC and WC; soil moisture deficit (SMD) was determined by the calculation method as the difference between MHC and the actual moisture.

**Results and discussion**

The process of soil formation in the study area proceeds on carbonate loess-like medium-textured loams. The total porosity is quite stable and varies from 39.0 to 40.0% of the dry soil volume (Table 1), MH: 12.1–12.6%, WC: 18.2–20.0%, MHC: 35.2–34.0%, TMC: 23.7–25.6%. Of all the moisture contained in the loess below the carbonate horizon which meets the MHC, a smaller part of it is available for plants: 15.0–16.0% on average 15.5%.

Table 1

Soil-hydrological constants of Calcic Chernozem

| Genetic horizons | Soil layer, cm | Specific gravity, g/cm³ | Volume density, g/cm³ | Porosity, % of the soil volume | % of dry soil weight |
|------------------|----------------|-------------------------|-----------------------|--------------------------------|---------------------|
|                  |                |                         |                       | MHC               | WC      | min.MHC | RAM    | TMC  |
| A1               | 0–10           | 2.63                    | 1.2                   | 54.3              | 5.3     | 8.0     | 32.3   | 24.4 | 45.2 |
|                  | 10–20          | 2.64                    | 1.43                  | 45.8              | 5.1     | 7.7     | 33.7   | 26.0 | 32.0 |
|                  | 20–30          | 2.64                    | 1.23                  | 53.4              | 3.8     | 5.7     | 26.3   | 20.6 | 43.4 |
| Bk1              | 30–40          | 2.67                    | 1.26                  | 52.8              | 5.3     | 8.0     | 26.1   | 18.2 | 41.9 |
|                  | 40–50          | 2.67                    | 1.29                  | 51.6              | 6.6     | 9.9     | 26.0   | 16.1 | 40.0 |
|                  | 50–60          | 2.69                    | 1.38                  | 48.7              | 6.4     | 9.6     | 23.4   | 13.8 | 35.3 |
| Bk2              | 60–70          | 2.68                    | 1.36                  | 49.2              | 5.8     | 8.7     | 24.5   | 15.8 | 36.2 |
|                  | 70–80          | 2.65                    | 1.36                  | 48.6              | 5.6     | 8.4     | 24.3   | 15.9 | 35.7 |
|                  | 80–90          | 2.66                    | 1.38                  | 48.1              | 5.9     | 8.9     | 24.6   | 15.7 | 34.8 |
|                  | 90–100         | 2.69                    | 1.40                  | 47.9              | 6.1     | 9.2     | 25.1   | 15.9 | 34.2 |
| Ck1              | 100–110        | 2.70                    | 1.40                  | 48.1              | 6.2     | 9.3     | 25.3   | 16.0 | 34.3 |
|                  | 110–120        | 2.70                    | 1.48                  | 45.1              | 6.6     | 9.9     | 26.7   | 16.8 | 30.4 |
|                  | 120–130        | 2.70                    | 1.52                  | 43.7              | 6.9     | 10.4    | 27.4   | 17.0 | 28.7 |
|                  | 130–140        | 2.69                    | 1.48                  | 44.9              | 6.8     | 10.2    | 26.8   | 16.6 | 30.3 |
|                  | 140–150        | 2.68                    | 1.32                  | 50.7              | 6.2     | 9.3     | 23.9   | 14.6 | 38.4 |
|                  | 150–160        | 2.68                    | 1.37                  | 48.8              | 6.5     | 9.8     | 25.9   | 16.1 | 35.6 |
|                  | 160–170        | 2.70                    | 1.45                  | 46.2              | 8.4     | 12.6    | 27.6   | 15.0 | 31.8 |
|                  | 170–180        | 2.70                    | 1.52                  | 43.7              | 9.2     | 13.8    | 29.8   | 16.0 | 28.7 |
|                  | 180–190        | 2.70                    | 1.56                  | 42.2              | 9.6     | 14.4    | 35.2   | 20.8 | 27.0 |
|                  | 190–200        | 2.70                    | 1.56                  | 42.2              | 12.6    | 18.9    | 35.2   | 16.3 | 27.0 |
| Ck2              | 200–210        | 2.68                    | 1.64                  | 39.0              | 13.3    | 20.0    | 35.1   | 15.1 | 23.7 |
|                  | 210–220        | 2.70                    | 1.62                  | 40.0              | 12.7    | 19.1    | 34.6   | 15.5 | 24.6 |
|                  | 220–230        | 2.69                    | 1.59                  | 40.8              | 12.4    | 18.6    | 33.9   | 15.3 | 25.6 |
|                  | 230–240        | 2.69                    | 1.60                  | 40.5              | 12.5    | 18.8    | 34.1   | 15.3 | 25.3 |
|                  | 240–250        | 2.70                    | 1.60                  | 40.7              | 12.5    | 18.8    | 34.1   | 15.4 | 25.4 |
|                  | 250–260        | 2.70                    | 1.60                  | 40.7              | 12.3    | 18.5    | 34.1   | 15.6 | 25.4 |
|                  | 260–270        | 2.70                    | 1.60                  | 40.0              | 12.5    | 18.8    | 34.0   | 15.2 | 25.0 |
|                  | 270–280        | 2.70                    | 1.60                  | 40.7              | 12.2    | 18.3    | 34.1   | 15.8 | 25.4 |
|                  | 280–290        | 2.70                    | 1.60                  | 40.7              | 12.2    | 18.3    | 34.1   | 15.9 | 25.4 |
|                  | 290–300        | 2.70                    | 1.60                  | 40.7              | 12.1    | 18.2    | 34.1   | 16.0 | 25.4 |

Reserves in the soil stratum occurs during the cold period of the year, from the end of October to the end of April. The growing season is characterized by the activation of moisture reserves in the soil.

In the autumn period (late vegetation period) in Prisamaya is enough amount of precipitation that in addition to low evaporation causes an increase in topsoil moisture. In addition to reducing evaporation, the accumulation of moisture in the soil is facilitated by continuous but low-intensity rains. At the same time, infiltration of soil moisture into the soil layers on the higher flat areas is possible only to a depth of 2 meters, as evidenced by the amount of moisture contained in the corresponding soil layer in higher amount than discontinuous capillary moisture and the zone of carbonate layer migration. Water movement is possible only as a film of moisture and in the form of steam under the influence of a temperature gradient, as well as molecular and capillary forces.

Analysis of changes in moisture reserves in the soil layer from the surface to 200 cm in thickness (Table 2) showed that the most active water exchange occurs in the range of soil layers from 0 to 150 cm. At the same time, the maximum possible reserves of active moisture (RAM) were found in the upper part of the organogenic horizons to their upper part.
soil layer of 50–150 cm; they were varied within the range from 31 to 322 mm and have an average amplitude variation of 226 mm. Within the range from 0 to 50 cm, the amplitude of seasonal changes in moisture reserves was 9–117 mm, with an average value of 55 mm. At the beginning of the vegetation period, the relative amount of active moisture in 0–50 cm layer was on average 52%, while the percentage of this category of moisture at the beginning of the growing season did not exceed 31%. This distribution was associated with an increase in capillary moisture during the inter-vegetation period and its downward migration along the soil profile. If we compare the relative changes in soil moisture during the season, the changes occur more dynamically in the 0–50 cm layer, but with less amount of moisture. This is easily explained by the influence of steppe vegetation, root systems of which can penetrate to a depth of 1 m or deeper.

Under these conditions, there is soil moisture deficit occurs throughout the year, which varies from 35 to 329 mm in the 0–200 cm soil layer depending on weather conditions. The average values of this indicator were shown in Fig 1a,b. For the end of the growing season (Fig.1a), there is a lack of moisture from 50 cm and below along the profile. The maximum values of this indicator were typical for the lower part of the two-meter soil layer. Hydrological state of the upper 50 cm of the topsoil depends more on climat e-forming factors and whether amount of precipitation falling onto the surface during the growing season will be sufficient for rainfall penetration. In addition, a relatively low soil density contributes to better rainfall penetration.

At the beginning of the growing season, penetration depth into the soil was more than 2 meters. In this layer, moisture deficit was reduced from 23 mm at the end of the growing season to 16 mm of the water layer, and the overall borderline of this indicator was reduced to 150 cm. Based on the dynamics of moisture deficit indicators, it can be assumed that the depth of atmospheric moisture penetration is below 200 cm.

At maximum rates of moisture deficiency, only strong xerophytes, such as Festuca sulcata (Hack.) Nym. Auct. ft. Ucr., Thymus marshallianus Willd., Salvia nemorosa L. e.t. remain in the vegetation cover. Softening the humidification conditions with minimal moisture deficit leads to the appearance of xeromesophytes and even mesophytes in the grass cover, such as Trifolius alpestre L., Potentilla argentea L., Phlomis tuberose L., Achilea millefolium L. p.p, Poa bulbosa L. etc.

Deficient water balance of soils was associated with the excess of evaporation over the amount of precipitation. In addition to the negative ratio of income and expenditure of the water balance, this phenomenon is associated with the low ability of soils to accumulate precipitation during the cold period of the year. So, according to some data (Gritsan, 2000), coefficient of precipitation accumulation in the cold period is 0.07 (defined as the ratio of precipitation to the amount of water in the soil stratum, in mm of water layer). The low value is promoted by the freezing of the soil during the cold period of the year. The warm period is characterized by even lower values of this indicator of 0.02, which is facilitated by surface runoff. The stable dominance of xerophytic vegetation in the vegetation cover indicates that, in general, the ratio of income and expenditure of the water balance remains unchanged in the long-term context.

### Table 2

The moisture content corresponding to RAM values in the soil
and more (in mm of the water layer)

| Soil layer, cm | Date of sampling | Soil moisture content, % |
|----------------|------------------|-------------------------|
|                | 08.10.2013       | 03.04.2014               |
| 0–10           | 15,8             | 18,1                     | 1.0 | 12,5 | 0.0 | 40,2 | 18,3 | 46,0 | 13,3 |
| 10–20          | 15,3             | 2,3                      | 13,0 | 12,2 | 0,0 | 17,2 | 7,8  | 23,6 | 6,8  |
| 20–30          | 13,6             | 19,9                     | 17,9 | 17,5 | 0,0 | 18,6 | 15,6 | 16,6 | 8,4  |
| 30–40          | 13,8             | 21,3                     | 17,1 | 16,6 | 0,6 | 21,8 | 12,7 | 31,2 | 14,2 |
| 40–50          | 3,6              | 20,3                     | 17,5 | 16,4 | 2,8 | 23,1 | 10,7 | 24,6 | 16,6 |
| 0–50           | 62,1             | 81,9                     | 66,6 | 75,2 | 3,4 | 120,8 | 65,2 | 142,0 | 59,3 |
| 50–60          | 4,6              | 21,8                     | 14,4 | 21,0 | 5,0 | 25,1 | 21,0 | 34,2 | 21,5 |
| 60–70          | 3,9              | 16,8                     | 0,0  | 22,5 | 3,7 | 23,5 | 1,6  | 51,8 | 17,6 |
| 70–80          | 2,4              | 15,8                     | 0,0  | 19,0 | 3,6 | 19,1 | 0,0  | 21,4 | 15,6 |
| 80–90          | 3,2              | 21,2                     | 0,0  | 22,4 | 3,5 | 27,5 | 4,3  | 31,7 | 12,9 |
| 90–100         | 1,6              | 16,7                     | 0,0  | 19,1 | 4,6 | 21,5 | 2,3  | 21,5 | 16,2 |
| 0–100          | 80,9             | 185,7                    | 80,9 | 199,2 | 26,6 | 250,6 | 78,0 | 315,9 | 158,3 |
| 100–110        | 3,1              | 11,4                     | 0,0  | 20,0 | 2,8 | 13,2 | 2,5  | 13,2 | 15,2 |
| 110–120        | 0,0              | 12,6                     | 0,0  | 14,8 | 0,6 | 19,4 | 1,2  | 19,4 | 10,2 |
| 120–130        | 0,0              | 8,8                      | 0,0  | 15,5 | 0,4 | 14,0 | 1,0  | 14,0 | 9,2  |
| 130–140        | 2,6              | 8,4                      | 0,0  | 13,4 | 1,8 | 18,9 | 2,8  | 18,9 | 9,2  |
| 140–150        | 6,2              | 9,6                      | 0,0  | 16,6 | 1,6 | 19,2 | 5,3  | 19,2 | 5,3  |
| 0–150          | 89,7             | 225,1                    | 80,9 | 259,5 | 30,9 | 322,2 | 87,4 | 387,5 | 192,3 |
| 150–160        | 2,1              | 8,9                      | 0,0  | 13,9 | 0,3 | 22,2 | 2,4  | 22,2 | 3,7  |
| 160–170        | 1,0              | 7,1                      | 0,0  | 9,3  | 5,7 | 13,9 | 2,0  | 13,9 | 3,7  |
| 170–180        | 0,0              | 4,4                      | 0,0  | 6,3  | 1,3 | 10,9 | 0,0  | 9,5  | 1,7  |
| 180–190        | 0,0              | 0,0                      | 0,0  | 0,0  | 0,0 | 4,9  | 0,0  | 1,9  | 0,0  |
| 190–200        | 0,0              | 0,0                      | 0,0  | 0,0  | 0,0 | 7,0  | 0,0  | 3,8  | 0,0  |
| Total amount   | 92,9             | 245,4                    | 80,9 | 289,0 | 38,1 | 374,1 | 91,8 | 434,9 | 201,4 |

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Conclusion

The distribution of water-physical properties in the Chernozem soil in the studied area occurs in accordance with the main genetic horizons. This is influenced by the content of carbonates, organic matter, and other parameters. Moisture in the soil profile is distributed unevenly and most of the active moisture (more than 90%) is in the range of depths from 0 to 150 cm. During the entire calendar year soil is characterized by a lack of moisture. There are no periods free from water deficit.

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Fig. 1. Soil moisture deficit: a – end of the growing season; b – beginning of the growing season, mm of water layer.