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The influence of temperature on the moisture potential in sod-podzolic soil in the autumn and winter periods of the year

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Abstract: The formation features of the potential and temperature dynamics at different levels of soil profile are revealed. The influence of soil temperature in the range of its high positive values on the dynamics of soil moisture potential is established. All lowering of the moisture potential occurs due to an increase in the moisture content. The increase in its content occurs due to precipitation and by pulling moisture from the underlying layers. In winter and in periods with negative temperatures, the moisture content is effected by diffusion of vaporous moisture, and in thawed soil, in liquid form.

Keywords: moisture potential, soil temperature, moisture exchange, aeration zone, the least moisture capacity, precipitation, moisture diffusion

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Introduction

Temperature is the most important thermodynamic parameter, functionally related to the soil moisture potential and significantly affects it. The influence of air temperature (Ta) and soil temperature (Ts) on the energy state of soil moisture and the intensity of its flow were studied by Globus (1977), Muromtsev, (1991), Mazhayskiy (2002), Durner, et al. (2006). However, the effect of soil temperature on moisture potential (Pc), in the region of high soil moisture (up to 0.7 of the lowest moisture capacity) and, especially in the range of low positive and negative temperatures, has been studied sporadically and quite insufficiently.

1. Methodology

Research into the dynamics of moisture potential and temperature of sod-podzolic weakly gleyed soil was organized at the Zelenograd base of the V.V. Dokuchaev Soil Science Institute. Regular observations began after the installation of the "Vantage Pro 2" automatic weather station and the installation of moisture potential and temperature sensors in the soil. The moisture potential sensors (length 70 mm, diameter 18 mm) and soil temperature sensors (length 30 mm, diameter 5 mm) were installed in sod-podzolic loamy soil (variant "a long period of uncultivated arable land") at depths of 5-12 and 5-8 cm (no. 1), 30-37 and 30-33 cm (no. 2), 50-57 and 50-53 cm (no. 3) as well 70-77 and 70-73 cm (no. 4).

The Davis 6440 soil moisture sensor was used to measure soil moisture pressure (Fig. 1). The soil moisture level is determined based on the value of the "soil suction pressure". The cylinder wall of the sensor watermark (diameter: 22 mm, length: 76 mm) is semipermeable (allows only water); inside the cylinder are two isolated electrical contacts and gypsum, the suction of the soil moisture; if the internal suction force sensor is more than in the soil, it absorbs water, if the suction force of the soil is greater than the sensor, the water is released; the suction force (suction pressure of soil water potential) is measured in santiburi.

Fig. 1. Sensor measuring the pressure of the soil moisture Davis 6440 soil moisture sensor (*own photo*)

"Soil suction pressure" measurement range: 0 to 200 centibar (cb), resolution: 1 cb; refresh interval: 62.5-75 seconds; soil moisture is characterized by the amount of vacuum created in the soil when the water runs out, a high value indicates dry soil; a watermark soil moisture sensor uses electrical resistance to measure the value of “soil suction pressure”. The Davis 6470 stainless steel temperature probe was used to measure soil temperature (Fig. 2). It is designed to measure the temperature of air, soil, water and other non-corrosive environments; it is commonly used to measure soil temperature in order to provide temperature compensation for Davis 6440 soil moisture sensors. Sensor type: platinum resistance thermometer with wire element; the sensor is securely sealed in a stainless steel cylinder. Cylinder diameter: 8 mm, length of the open part of the cylinder: 32 mm; maximum diameter (at the place of covering the steel cylinder with vinyl protection): 11 mm; temperature measurement, range: –40-+65°C, accuracy: ±0.5°C; refresh interval: 62.5-75 seconds. The 22 AWG double-strand cable is resistant to pests, water and ultraviolet light. To ensure the accuracy of the readings when measuring air temperature, the sensor was shielded from direct sunlight and other sources of reflected or radiated heat.

Fig. 2. Sensor measuring the temperature of the soil Davis 6470 stainless steel temperature probe (*own photo*)

Information from the sensors of moisture potential and soil temperature goes from the switch (Fig. 3) to the display of the collection and primary processing of weather station data (Manual, 2009), and then - to the computer. Sod-podzolic weakly gleyed soil in the “a long period of uncultivated arable land” variant is sufficiently represented in the work (Muromtsev & Anisimov, 2014).

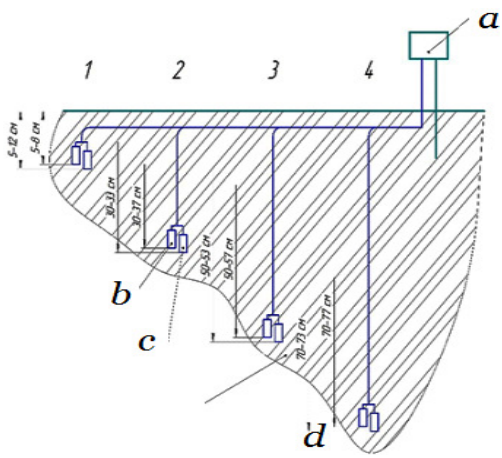

Fig. 3. Arrangement of soil sensors (a - repeater, b - soil temperature sensor (t [°C]), c - sensor dynamics of soil moisture pressure (P [kPa]), d - soil sod-podzolic medium loamy) (*own figure*)

2. Results and discussion

Information about dynamics of moisture potential and soil temperature in the autumn and winter periods 2014-2015 is analyzed within each given date at intervals of every 3 hours (for example, 3 am on November 21, 2014). The dynamics of the potential of soil moisture most noticeably changes in the upper layer (5-12 cm) in the autumn and winter periods 2014-2015. Its summer and early autumn values ranged from 150 kPa to 5-7 kPa depending on the degree of soil watering. At the beginning of December, they “soared” up to 200 kPa and remained at this high level for three weeks. However, at the end of December, the potential in the upper soil layer dropped to 40-35 kPa, and approached its values in the thickness of 30-77 cm. The dynamics of the potential in the layers of 30-37, 50-57 and 70-77 cm was calm during most of the autumn, reaching a maximum of 80-65 kPa. By the end of October and partially in November, the potential values decreased to the level of 40-35 kPa. Furthermore, by December and at the beginning of the month, the temperature went into the region of low negative values (–1-–2°C) in the layer of 5-12 cm, and it decreased to low positive values (0.7-1.5°C) in layers of 30-37, 50-57 and 70-77 cm. These values did not change significantly throughout the winter and early spring, up until April 5 (Figs. 4, 5).

This nature of potential changes in different layers of thin soil layers (77 cm) is entirely explained by the features of moisture exchange in the aeration zone and the temperature course in the layers of installation of the potential and temperature sensors. At the beginning of November (6th), the low values of positive temperatures in the layers of 30-33, 50-53 and 70-73 cm were respectively +3.2, +3.1 and +3.9°C, and in the upper layer (5-8 cm) - negative value (–2.8°C). It follows that the difference of the values in the upper and lower layers of 6.7°C (–2.8-+3.9) degrees is significant in the case of low values of temperature (–2.8 and 3.80°C). In the middle layers of the soil (30-33 and 50-53 cm), the temperature is almost the same. Subsequently, over a three-week period (November 6-21), the soil temperature had the following course: By November 13, it increased and went up to 4.3, 4.4 and 4.9°C in layers of 5-8, 30-33, 50-53 and 70-73 cm, i.e. increased by 1-1.5 degrees (throughout the depth), and almost leveled off within the four layers of soil.

However, the temperature decreased to 0.20°C in a layer of 5-8 cm in November. In the two middle and lower layers, it reached values of 1.9, 1.7, and 3.0°C, respectively. A sharp decrease (from 4.3 to –0.1°C) in the surface layer led to an increase in the moisture potential to 200 kPa. That high value was observed until December 17. Then a gradual decrease was noted: 18th of December - 182 kPa, 19th of December - 137 kPa, 20th of December - 107 kPa, 21st of December - 83 kPa and 25th of December - 37 kPa. And at this level (37-39 kPa), the moisture potential in the upper layer remained through January and the beginning of February 2015.

Considering the daily dynamics of the potential and soil temperature for some of the most characteristic dates of November 2014-February 2015. By 00:00 on November 11, 2014, the potential amounted to values in the range of 41-39 kPa in layers of 5-12, 30-37, 50-57 and 70-77 cm. However, by the end of the day (24-00), the potential value in a layer of 5-12 cm increased to 200 kPa very sharply and significantly. In layers of 30-37, 50-57 and 70-77 cm, the potential did not change and remained at the same levels. The reason is a sharp decrease in soil temperature at the depth of 5-12 cm to 0.00°C, at all other depths, the temperature remained at the same level.

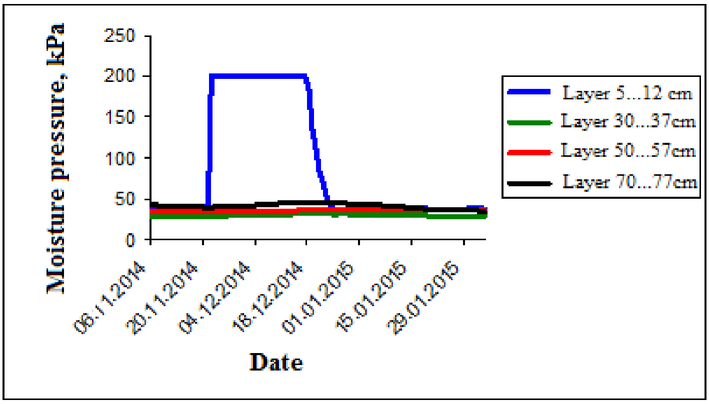

Fig. 4. Dynamics of moisture pressure in the variant "a long period of uncultivated arable land" for the period November 6, 2014-February 3, 2015 (*own research*)

Subsequently, until December 20, the temperature in the upper soil layer remained at the level of 0.0-0.1°C; during this time the potential decreased by 00:00 to 123 kPa, and by the end of the day - to 96 kPa. The temperature in the middle layers of the soil (30-33 and 50-53 cm) were 0.6-0.7°C, in the bottom layer (70-73 cm) - 1.4-1.5°C. By 00:00 on December 25, the potential values decreased to 40, 32, 36, and 45 kPa in layers of 5-12, 30-37, 50-57, and 7-77 cm. The soil temperature in all layers remained at the same levels. Consequently, under conditions of a sharp change (decrease) in soil temperature to negative values, the moisture potential can significantly vary even within a few hours.

Throughout January, the temperature at all depths was maintained almost at the same levels: 0.1-0.2, 0.7-0.8 and 1.4-1.5°C in the layer of 5-8, 30-33, 50-53 and 70-73 cm. By the beginning of February, it was almost unchanged, remaining at the same levels in all layers of the soil. Moisture potential was also observed in the range of previous values, decreasing by only 1-2 kPa in layers of 5-12, 30-37 and 50-57 cm. Its values significantly decreased (45-34 kPa) only in the layer of 70-77 cm. This decrease in potential occurs due to a decrease in the moisture content, which is carried out as a result of its movement upward under the action of a temperature gradient to the freezing zone or strong cooling (Muromtsev, 2007).

Sudden or significant changes in moisture potential during these periods were not observed.

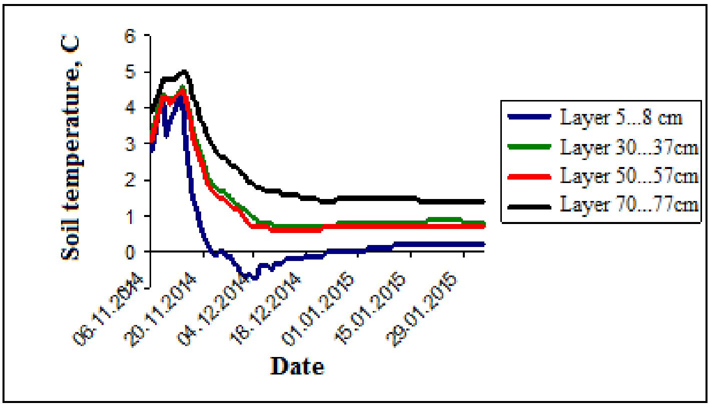

Fig. 5. Temperature dynamics in the variant "a long period of uncultivated arable land" for the period November 6, 2014-February 3, 2015 (*own research*)

A distinctive feature of the dynamics of the moisture potential in late autumn and winter periods is, firstly, that both an increase and a decrease in potential (in absolute value) are observed at about zero temperature (–0.1°C÷+0.2). Another feature is that at almost the same temperature of the soil (in the region near its zero values), the potential at different dates varies greatly in magnitude. At the same time, the daily dynamics of the potential can vary over the course of one day by 30 or more kPa, and in some cases - several times (Figs. 4 and 5).

From 00:00 on December 20 to 00:00 on December 21, the soil temperature in the layer of 5-8 cm decreased 0.2-0.0°C; in the layers of 30-33 and 50-53 cm - within 2.0-2.1, and in the layer of 70-73 cm - 3.2°C. The moisture potential in the 5-12 cm layer changed during the day as follows: 41 kPa (00:00), 42 kPa (18:00), 200 kPa (24:00). Therefore, in one day the potential value increased (41-200 kPa) five times with a very slight decrease in temperature in this layer of soil (0.2-0.0°C). Later (November 22, 2014), in case of a decrease in temperature of –0.1°C, the potential value did not change and kept at the level of 200 kPa until December 19, 2014, and after a day (December 20, 2014) at a constant temperature (–0.1°C) decreased to 123 kPa, and a day later - to 99 kPa. The following small temperature increase to 0°C (December 25) seemed to lead to a decrease in the potential to 40kPa, while a further increase in temperature to 0.2°C had no effect on the potential and its value at the level of 38-37 kPa was observed till February 4, 2015.

Hence, as noted above one obtains that small changes in temperature within its zero values (–0.1°C÷+0.2) hardly affects the value of the moisture potential. The reason for this is probably the change in the moisture content in the freezing (or strong cooling) zone of the soil. These changes in the moisture content are caused by both evaporation (freezing out) of moisture from the freezing layer and its migration from the underlying warmer and wetter layers of the soil (Muromtsev, 1991). The speed of these processes (freezing evaporation and moisture migration) is very low, therefore, considerable time is required to accumulate or reduce the moisture value to a kind of critical value, after that, the potential value increases or decreases. It is also interesting that in the soil thickness of 8-73 cm, the potential value did not change during these days and was in the range of 29-40 kPa. The high value of the potential (200 kPa) continued to remain until December 20.

From midnight on December 20 to 21, the soil temperature in the upper layer (5-8 cm) continued to remain at the level of 0.1°C, in the layer of 50-53 cm - within 0.6-0.7°C, and in the layer of 70-73 cm - 1.5°C. The value of the potential during the day changed as follows: 123 kPa (00:00), 108 kPa (12:00), 101 (18:00) and 37 kPa (24:00). Hence, the moisture potential within one day decreased three times (123-37 kPa) while maintaining almost the same temperature values in the layer of 5-8 cm (0.0-0.1°C).

After that, the moisture potential at all depths of the soil continued to decrease very slowly. In the upper layer (5-12 cm) over the course of the month (February 5 to March 5, 2015) it decreased to 31 kPa (by 6 kPa), in the layer of 30-37 cm - to 23 (by 5), in the layer of 50-57 cm - up to 24 (by 11) and in the 70-77 cm layer - up to 23 kPa (by 11 kPa). The soil temperature over this period practically did not undergo any noticeable changes, reaching, as before, values in the range of 0.20-0.4°C, 0.8-0.9, 0.7-0.8 and 1.3-1.4°C, respectively, in layers of 5-8 cm, 30-33, 50-53 and 70-73 cm.

The slow and insignificant decrease in potential values noted above, as well as the more significant and faster changes, occur due to an increase in the moisture content in the analyzed soil thickness (0-77 cm). Moisture increase in thawed soil occurs after precipitation, and in soil frozen from above - by pulling it from the underlying, more waterlogged layers. In winter, with low positive and negative temperatures, the moisture migration from the lower, warmer and wetter layers of the soil to the freezing (or strong cooling) front is carried out by the diffusion of vaporous moisture. In thawed soil with positive temperature dynamics, in the form of vapor diffusion and in liquid form. The driving force of moisture transfer is the gradients of temperature and moisture potential.

A decrease in the moisture potential (in case of constant humidity) with increasing temperature is explained by an increase in the mobility and activity of moisture. The latter leads to an effect similar to an increase in its content.

Conclusions

Thus, one obtains that the moisture potential decreases in the case of an increase in soil temperature, and increases in the case of a decrease in its temperature.

This is due to the fact that the surface tension of water decreases; an increase in water temperature from 0 to 50°C causes a decrease in the surface tension of water of 7.73 decinewton/cm. Since an increase in temperature causes a decrease in the surface tension of water, the energy costs for extracting a unit of water mass (volume) from the soil decreases. The soil moisture becomes more mobile and active. The degree of change (increase or decrease) in the potential depends on the moisture content and water-physical properties of the soil.

The degree of change in soil temperature during the day is not significant and lies within 1.5°C in the upper and 0.4-0.3°C in the lower soil layers, approaching zero with the depth and stabilization of the moisture content. Changes in the moisture potential during the day are in the range of 2-3 kPa. The highest potential values are in the upper layer of 5-12 cm, from which the greatest moisture loss due to evaporation occurs. Under conditions of a sharp change (decrease) in soil temperature to negative values, the moisture potential can significantly vary even within a few hours.

All kinds of potential changes (slow and slight, fast and significant) occur due to changes in moisture content and soil temperature. The decrease in potential with increasing temperature (in conditions of constant humidity) is explained by an increase in the mobility and activity of moisture. At almost the same temperature of the soil (in the region near its zero values), the potential at different dates can vary greatly in magnitude.

In winter, with low positive and negative temperatures, the moisture migration from the lower, warmer and wetter layers of the soil to the freezing (or strong cooling) front is carried out by the diffusion of vaporous moisture. In thawed soil with positive temperature dynamics, - in the form of vapor diffusion and in liquid form. The driving force of moisture transfer is the gradients of temperature and the moisture potential.

Bibliography

Durner, W. & Or., D. (2006) *Soil Water Potential Measurement*. Encyclopedia of Hydrological Sciences. Apr., 1-14.

Globus (1987) *The soil-hydrophysical support of agroecological models*. Leningrad, Hydrometeoizdat.

Installation and use manual for the "Vantage Pro 2" automatic weather station. (2009). Howard. 63.

Mazhayskiy, Yu. (2002) *The substantiation of complex amelioration regimes under the conditions of technogenic pollution of the agrolandscape.* Moscow.

Muromtsev, N. (1991) *Reclamation Hydrophysics of Soils.* Leningrad, Hydrometeoizdat.

Muromtsev, N. & Anisimov, K. (2014) *Some features of the formation of the sod-podzolic soil water regime on various elements of geomorphological catena*. Bulletin of the Soil Institute, Moscow, 77, 78-93.

Wpływ temperatury na potencjał wilgoci w glebie sodowo-bielicowej w okresach jesiennych i zimowych roku

Streszczenie: Opisano dynamikę potencjału wilgotności i temperatury na różnych poziomach profilu glebowego. Ustalono wpływ temperatury gleby w zakresie jej wysokich dodatnich wartości na dynamikę potencjału jej wilgotności. Wzrost wilgotności występuje w związku z opadami atmosferycznymi i poprzez odciąganie wilgoci z warstw leżących poniżej. W okresie zimowym oraz w okresach ujemnych temperatur występuje dyfuzja pary wodnej, a przy dodatnich temperaturach przepływ wody.

Słowa kluczowe: potencjał wilgoci, temperatura gleby, wymiana wilgoci, strefa napowietrzania, najniższa pojemność wilgoci, opady, dyfuzja wilgoci