Monitoring the temperature of the upper soil horizons in field crops in the Krasnoyarsk forest-steppe

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Abstract. The research was carried out in 2019 at the test fields of Krasnoyarsk Research Institute of Agriculture of the Federal Research Center Krasnoyarsk Science Center SB RAS located in the village of Minino, Yemelyanovsky District. Sensors were installed in spring wheat, spring barley and spring rapeseed to record soil temperature at different depths (0, 5, 15 cm). Temperature data were recorded hourly, at the beginning of each hour. Soil temperatures were recorded at different depths and registered for the main stages of plant development for different field crops. Studies have shown that the largest daily fluctuations in soil temperature occurred in the upper horizon for all the studied field crops. In 5 and 15 cm horizons soil temperature was less exposed to daily fluctuations. The dynamics of changes in soil temperature was monitored with the special focus on the stage of plant development. In the stage of seedlings, when the surface horizon of the soil is open, the greatest daily fluctuations were fixed; with the increase in biomass, the shading of the soil surface changed, while the soil temperature in the upper horizons decreased.

1. Introduction

Soil temperature is one of the most important factors in the life of plants and soil microorganisms. Seed germination begins only when the soil is heated to certain values specific for this very type of plants. The rate of seed germination surges with rising soil temperature, which reduces the period from sowing to seedlings [1].

Lower temperature in the root area delays the growth of aboveground and underground organs. Numerous studies have shown that the soil temperature in the horizon of 0-20 cm at 20-25°C raised the yield of cold resistant crops twice, heat-resistant crops – by 2-3 times, on the contrary, a decrease in soil temperature to 10-12°C for cold resistant crops and to 10-14°C for warm-season crops diminished yield by 2-3 times [2]. Soil temperature has a major impact on root growth. Low (below 5°C) and high (above 30°C) soil temperatures contribute to the fact that roots do not go below the surface horizon, and their growth and development suffer. Most plants have the most powerful, branched root system formed at soil temperature of 20-25°C [3]. Higher soil temperature has a negative effect on plants, causing a
slowdown in seed development. The temperature regime of soil is closely related to the spread and harmfulness of diseases and pests of agricultural plants.

Soil temperature has a critical influence on the process of plants’ absorption of mineral elements. Plants’ absorption of nitrogen and phosphorus at a soil temperature of 5°C is almost 3 times less than at 20°C. The vital functions of microorganisms, along with the uptake of nitrogen and phosphorus improve with increasing soil temperature [4,5].

It is essential for agriculture specialists to take into account the temperature regime directly during the sowing. In plant communities the range of air temperature may be significantly different than in a field free from plants. The difference between the temperature regime of vegetation-free soil and the plot with field crops depends on the thickness of vegetation, the denser and higher the plants are, the thicker is the cover the top tier of leaves forms [6].

In thickened crops there is observed a complete shading of the soil. The working horizon here is the upper tier of leaves, which absorbs most of the incoming solar radiation. If the degree of soil shading by plant cover is less than 50%, the temperature range in the field crops is slightly different from the temperature range for the plot without vegetation. The working horizon in this case is the uppermost soil horizon. Therefore, the daily maximum and minimum temperatures are registered on the soil surface. Such a vegetation cover is typical of the initial stages of plants’ development [7].

Hence, to properly evaluate crop growth conditions and to ensure the most efficient use of fertilizers and crop protection agents, specialists should take into consideration the information on soil temperature.

2. Materials and methods

The climate of the area of the test site is sharp continental, with cold long winters and short hot summers. The average multiannual air temperature is 0.7°C with July being the warmest month, January – the coldest. The period with an average daily air temperature above 0°C lasts 182-192 days. The average temperature in January is -16.8°C, while the average temperature in the warmest month (July) is 18.5°C. The duration of the growing season is 123 days. The sum of active temperatures (+10°C and more) is 1600-1800°C [8].

The soil of the experimental plot is represented by leached black-soil, low-power, low-humus, moderately degraded, heavy loam granulometric composition. Average humus content is 3.6%, which characterizes the chernozem under study as slightly humic (<4%) with low content of organic matter. The content of nitrate nitrogen is low, too (3.4 mg/kg), but the content of movable phosphorus is rather high – 21-23 mg/100 g of the soil and the content of potassium is also high – 15.2 mg/100 g of soil, as according to Chirikov’s calculations.

Phenological visual observations of plant growth and development at the experimental plots were made twice and also in the time of counting the number of plants having entered this stage. The moment when 10% of plants entered the stage of growth and development was considered its beginning, the end of this stage marked the moment when 75% of plants entered this stage. Field germination of seeds was calculated four times and the calculations took into the account the actual thickness of plants and the norm for seed sowing. The thickness of plant stand was counted twice during the growing period: in the stage of fully grown seedlings and before harvesting.

To figure out temperature trends in soil horizons there were used autonomous temperature loggers (data loggers) of “EClerk-M” company. The measuring element was chromel-aluminum thermocouples of factory production (“RELSIB”, Russia). Temperature measurements were made by laying the vertical soil profile with 3 measurement points in each, at a depth of 0, 5, 15 cm from the soil surface. During the field season (June-September, 2019) 8 soil profiles were made, each consisting of 22 data sets (2 were lost). Temperature data were recorded hourly, at the beginning of each hour. Sensors were installed for different types of crops (spring wheat, spring rape, barley). The profile site was located in the experimental fields of the Federal Research Centre “Krasnoyarsk Science Centre” of the Siberian Branch of the Russian Academy of Sciences adjacent to the village of Minino, Yemelyanovsky District, Krasnoyarsk Krai. The profiles were set on an area of 1 km². Those installed on June 11, 2019 were
colored red, and in blue – those installed on July 11, 2019. Data collection from soil profiles was conducted prior to the start of harvesting crops from the fields.

![Figure 1. Location of temperature profiles at the experimental site.](image)

Location of points on the experimental fields and the studied crops: spring wheat – Altayskaya variety 70 – M1, M2, M6, M7; spring rape – Nadezhny variety 92 – M5, M8; spring barley – Abalak variety – M3.

3. Research Results

The beginning of the vegetation period in 2019 was characterized by the lack of moisture in the period of seedlings growth (the amount of precipitation was 18.7-24.0 mm lower than the average annual norm). Spring rapeseed sown in the first period (May 25) underwent drought in late May – early June. The quantity of plants in the stage of seedlings at point M5 was 65.0 pcs/m², so field germination was low. By harvesting there were only 45.0 pcs/m², survival rate by harvesting at the point M5 totaled 69.2%. Soil temperature during the period when spring rapeseed seedlings started to grow was 33-41°C, in the horizon of 5 cm depth there were fluctuations of temperature from 16 to 19°C. The soil surface was completely open, the number of seedlings was insignificant, with weed plants found in-between crops. In the stage of formation of 4-5 leaves after heavy rainfall in late June, spring rapeseed biomass began to grow actively and close the soil surface, the amount of seedlings increased, but planting thickness remained low. Soil temperature in the upper horizon of soil was 34-50°C, in the horizon of 5 cm deep –19-24 °C.

In the stage of stem extension, the biomass continued to grow, the height of sown plants was 55-57 cm, the area of leaf surface – 130.9 cm². The planting remained spaced; a large number of weed plants were detected in it (figure 2). Soil temperature in this stage of development was 36-54°C in the upper horizon, and in a horizon of 5 cm depth – 21-24°C. High air temperature and sparse planting contributed to the increase of soil temperature.

Spring rapeseed sown in the second period (July, 2) got into favorable conditions, both in terms of moisture, and the temperature of air and soil. The number of plants at the point M8 in the stage of seedlings was 96.0 pcs/m2, by harvesting it decreased to 82.0 pcs/m2, the survival rate by harvesting at the point M5 reached 88.2%.
In the stage of 4-5 leaves (July, 27) spring rape experienced an active growth of biomass, with plants closing soil surface, with the height of plant being on the average 11.2 cm, the area of leaf surface – 113.3 cm\(^2\). Soil temperature in the upper horizon during daytime ranged from 36 to 43°C and the temperature in the lower horizons was slightly lower.

![Figure 2. Measuring point (M5), spring rape culture, stage of the anthesis beginning.](image)

In the stage of stem extension (August, 7) the height of plants increased to 62.4 cm, the area of the leaf surface – up to 234 cm\(^2\). Since this period, a decrease in soil temperature in all the studied profiles was observed.

In the stage of budding (August, 21) the average height of plants in sowing was 88.5 cm, the area of leaf surface enlarged. During this stage there was the tendency of declining temperature of soil for all investigated profiles. In the upper horizon of the soil the daytime temperature ranged from 28 to 34°C, in horizons of 5 and 15 cm depth fluctuations in soil temperature were 16-18°C.

In the stage of anthesis (September, 1) there was the maximum height of plants and the area of the leaf surface (figure 3). Soil temperature in the field crops continued to fall both owing to the large biomass of spring rapeseed and because of the decreased air temperature. During this period, the soil temperature in the upper horizon was on average 23-29°C, and in horizons of 5 and 15 cm depth – 15-20°C.

Thus, in 2019 the second term of sowing (July, 2) occurred under optimal conditions of moisture and temperature of both air and soil, which contributed to the emergence of beautifully arranged sprouts of spring rape, good plant development and a high yield of green mass.

Spring wheat of Altayskaya 70 variety was sown on May 22 at the point M6 and on May 26 – at the observation points M1, M2, M7. The quantity of plants in the stage of seedlings was different – at the point M1 the number of plants was greater, at the points M2, M7 planting was sparse. At the moment of installation of sensors in spring wheat at points M1 and M2 there began the stage of seedlings – tillering (Table 1). The soil surface in the field was still quite open, so the fluctuation of soil temperature during the day in the upper horizon was significant, reaching peak values of 50°C and dropping to 16-18°C at night. The soil temperature in the deeper horizons of the soil was less subject to fluctuation. Spring
wheat plants started to cover the soil surface in the stage of tillering (June, 19-23), but at M2 point the planting was thin due to low germination. Variations in soil temperature in this stage in field crops were also quite meaningful in the upper horizon, but the deeper horizons of soil showed a tendency that the minimum soil temperature increased, which can be explained by heating of soil.

![Image of a field with crops](image)

**Figure 2.** Measuring point M8, spring rapeseed culture, stage of the anthesis beginning.

**Table 1.** Main stages of cereal crops development, Minino village, 2019.

| Development stage | Spring wheat Points M1, M2, M7 | Spring barley, point M3 |
|-------------------|--------------------------------|------------------------|
| Seedlings         | June, 8                        | June, 5                |
| Tillering         | June, 23                       | June, 19               |
| Exit to the tube  | July, 2                        | July, 1                |
| Earing            | July, 16                       | July, 15               |
| Full ripening     | August, 29                     | August, 26             |

In the stage of ear formation (July, 15-16) the spring wheat biomass continued to grow, the soil was completely closed by the field crops, all this affected the soil temperature and there was a general trend of the declining temperature in the upper horizon of the soil as compared with June. Deeper soil horizons were less susceptible to fluctuations in soil temperature during the day.

At the moment of installation of sensors for spring barley (point M3) there began the stage of fully grown seedlings – tillering. As well as in the sowing of other crops, there was a considerable change in soil temperature in the upper horizon during the day, for example, on June 12 the temperature ranged from 13°C at 01.00 to 36°C at 13.00, but at the depth of 5 cm and 15 cm fluctuations in daily temperatures were insignificant.
During the tillering stage (June, 20) the soil surface was hidden by field crops. Compared with June, the soil temperature in the upper horizon began to decline, but at the depth of 5 cm and 15 cm there was indicated heating of the soil and an increase in minimum temperatures.

The ear formation stage was recorded on July 16, a trend of lower soil temperature in the upper horizon was also registered in this stage of plant development. The height of plants was 54-56 cm during this stage. Soil temperature in the upper horizon was 30-37°C in the daytime, and at night – 16-19°C, at a depth of 5 cm – 23-26°C during the day, at night – 19-21°C. At a depth of 15 cm the temperature reached 23-25°C in the daytime, and at night – 19-21°C.

4. Conclusions

There was conducted a study of soil temperature in three soil profiles (0, 5, 15 cm). The biometric parameters of stages of field crops (spring wheat, spring barley, spring rapeseed) and dates of their development stages were indicated.

The research has shown that the greatest daily fluctuations in soil temperature occurred in the upper horizon in all studied field crops. In 5 and 15 cm horizons soil temperature was less exposed to daily fluctuations.

The dynamics of soil temperature changes depending on the stage of plant development. In the stage of seedlings, when the surface horizon of the soil is open, the largest daily fluctuations are observed. With the increase in biomass, the shading of the soil surface changes and the soil temperature in the upper horizons decreases.

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