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TEMPERATURE AND THERMAL PROPERTIES OF SOIL IN TRACTOR WHEEL TRACK AS THE EFFECT OF LOCAL SOIL COMPACTION AND MICRORELIEF

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A b s t r a c t. The influence of local soil compaction and microrelief on the distribution of temperature in cross-section of the doubled track of a tractor wheel, was analyzed. Topsoil temperature differentiation within the track reaching 8 °C around noon was observed during a sunny summer day. Simultaneoulsy, as the result of higher bulk density and moisture of the soil, higher values of thermal properties of soil in the track compared to the field were stated. Differences in particular thermal properties of soil in the 0-5 cm layer between the track and the field in relation to the mean values of the field were above 20 % in the case of volumetric heat capacity and about 150 % in thermal conductivity of soil.

K e y w o r d s: soil compaction, temperature, thermal properties, microrelief, tractor wheel track

INTRODUCTION

A side-effect of tractor and other agricultural machines working in cultivated fields is local compaction of soil under wheel tracks. The degree of compaction depends on the type and physical state of the soil at the moment of making the track and on technical parameters of the vehicle [11]. Wheel tracks on cultivated fields can be treated as a disturbance in spatial distribution of bulk density and other physical properties of soil, often staying for the whole vegetation season [1,2,9]. Soil compaction in wheel tracks influences the soil structure, a plant's root system growth, and crop yields [1,8,10]. Moreover, wheel tracks are a significant element of microrelief on the surface of cultivated fields, especially in freshly loosened soil. Physical properties in addition to soil microrelief, influence, directly or indirectly, the processes of mass and energy flow in soil, and these subsequently influence the temperature of the soil.

It has already been reported that in the top layer of compacted soil both the 24 h amplitude and the temperature during the day decreased as compared to loose soil [5,6]. Temperature differentiation caused by the differences in physical properties of soil (density, moisture, thermal properties) as well as the dynamics of temperature changes in time are damped by the plant and cloud cover, as the result of less solar radiation reaching the soil surface [3,7,15]. Therefore the studies on the influence of physical properties or soil cultivation measures on its temperature are most of all conducted on bare soil during cloudless days, i.e., in conditions in which this influence can be the greatest (easily observable). If there are wheel tracks, two additional factors influence the soil temperature, and should be taken into consideration. They are: track shape (width, depth, presence or absence of traces of tire tread), and the track's orientation. They determine the exposition of particular parts of the track to direct solar radiation, and cause topsoil temperature differentiation within the track.

The aim of this paper is to investigate the influence of local soil compaction and micro-relief on the temperature distribution within a tractor wheel track, as well as to determine the differentiation of soil thermal properties on cultivated field without crops, when the wheel tracks are observed.

OBJECT AND METHODS

The research was carried out in a field kept in the state of black fallow with loess-like silty soil in Felin, near Lublin (next to the Agrometeorological Station of the Agricultural University of Lublin). Immediately after loosening the soil with a cultivator and a harrow on April 21st 1993, an Ursus C-360-3P tractor drove back and forth (on the same track) through the field. The track made in this way was over 4 cm lower in the central part than the edge, and the shape of tractor's rear tyre tread was easily visible. The track remained unchanged till the last measurements in the middle of July.

Soil temperature was measured at 7 points within the track and - for comparison - at points outside the track (Fig. 1), using a multisensor thermoelectric thermometer, installed on April 27th. The measuring system used [4], consisted of a set of interconnected thermometric probes (including separated probes with reference thermocouples installed 1 m deep in the soil and in a mixture of water and ice), a transmission line, a commutator

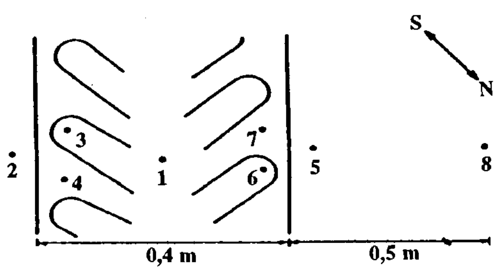

Fig. 1. Localization of measurement points of soil temperature on the object of research. 1 - centre of the track, 2 - close to the eastern edge of the track, 3 - concavity after the tyre tread on the eastern side of the track, 4 - convexity after the tyre tread on eastern side of the track, 5 - close to the western edge, 6 - concavity after the tyre tread on the western side, 7 - convexity after the tyre tread on the western side, 8 - outside of the track.

and a microvoltometer. This system allowed remote readings of the temperature from each of the 54 sensors, from successive depths beginning with the nearest to the soil surface. The depths of soil temperature measurements at particular points were as follow: in the centre and outside of the track - 1, 2.5, 4, 6, 8, 10, 12.5, 15, 17.5, 20, 23, 26.5 and 30 cm; in convexities made by the tyre tread within the track - 1, 2.5, 4, 6, 8, 10 and 12.5 cm; in concavities made by the tread - 1, 4 and 10 cm; close to the external borders of the track - 1, 4, 10 and 20 cm. In principle, the temperature was only measured during days with sunny weather, which had a positive influence on soil temperature differentiation.

Besides the temperature, soil moisture in arable layer was measured, using the gravimetric method. Soil samples were taken from the following layers: 0-1, 1-3, 3-6, and for all subsequent 3 cm layers, in places matching the position of the thermometric probes (at a distance of about 1 m from them) and at points 1 and 10 m distance from the track. After the last series of temperature measurements, on July 15, near every thermometric probe and in the places of soil moisture measurement outside the track, soil samples were taken in order to determine it's bulk density (into cylinders with 25 cm^3 volume and 2.5 cm height). At every point, soil samples were taken at least twice (except for the concavities and convexities from the tyre tread). It should be mentioned that bulk density and moisture of soil in arable layer around the track was also determined during the making of the track; soil samples were taken into the cylinders of 100 cm^3 volume and 5 cm height.

Measured values of bulk density, moisture and temperature of the soil became the base to estimate the thermal properties of the soil using calculation methods. Volumetric heat capacity was calculated according to the de Vries' formula [14], thermal conductivity from the statistical-physical model [12,13], and thermal diffusivity from the relation of the values of thermal conductivity and volumetric heat capacity of the soil.

In order to obtain comparable data of layers with particular thickness and close to a natural distribution (in a continuous way) with the depth of particular physical properties of soil, the values of soil moisture and bulk density from the measuring points underwent proper statistic processing. Ascribing the value measured for the given soil layer to the depth in the middle of the layer, using the cubic-splines technique, the distribution of bulk density and moisture of soil with the soil depth has been found and, basing on it, the mean values for chosen layers have been calculated.

This paper is based on the results of measurements from two days: 2nd and 10th of July 1993. They were chosen for characterizing the thermal properties of soil after long rainfall and then a few days of sunny weather permitting for soil drying. It should be added that two decades preceding the measurements were rainy (16 days of rain of the total amount of 59 mm), and the last rain had been recorded three days before. The measuring data from July 10th 1993 were used as an example of the development of soil temperature distribution in the tractor wheel track and its changes during the sunny summer day. On that day the measurements of temperature were carried out every 30 minutes, beginning from 05,40 a.m. (about an hour after sunrise) till 08,40 p.m. (sunset), and the measurements of soil moisture - around noon. It was a hot, mostly cloudless day (clouds of the Cu type appeared only around noon in an amount not greater than 2/8). Minimum and maximum air temperature was 11.1 and 25.6 °C, respectively, and the daily sum of the total solar radiation was 2812 J cm^{-2}. Because of the track's orientation, approximately from NW towards SE, the shadow of the vertical pointer fell at a right angle to the track at around 10,00 a.m. and 07,00 p.m., and parallel to the track at around 02,00 p.m.

RESULTS

The mean moisture and bulk density of soil on the experimental field before its compaction with the tractor wheels in successive layers 0-5, 5-10, 10-15 and 15-20 cm were 0.20, 0.21, 0.22 and 0.23 g g^{-1} and 1.149, 1.243, 1.395, and 1.502 Mg m^{-3}. The increase in the soil bulk density on the field, during the period from starting the experiment to the end of measurements (8 decades), was observed only in the 0-10 cm layer (by about 7-8 %), while deeper it was not significant (about 1 %). During that period in 31 days the rainfall was greater than 0.1 mm and the sum of the rainfall was 98 mm, the maximum 24 h rainfall was 28 mm.

The major factor influencing the thermal properties and temperature of soil, besides density, is its moisture. As can be seen in Fig. 2, the distribution of soil moisture with depth in- and outside the track, in both investigated days (July 2nd and 10th), show generally approximate values within the arable layer, especially on the second day. However, the interesting thing was the higher soil moisture of the surface 0-1 cm layer in the track, compared to the field (by about 0.04 gg^{-1}) on the first day, but after eight days it was almost equal. That means, that the soil in that layer was drying faster on the field than in the track.

The distribution of bulk density and temperature of soil in cross-section through the tractor wheel track

The installation of the measuring points along the line across the track (Fig. 1) allowed a reconstruction of distribution of soil bulk density and temperature in cross-section through the track. Making the reconstruction, technique of cubic-splines and the method of linear interpolation were used, respectively for the determination of the distribution of values vertically at the individual point and horizontally between the measuring points. The distribution of soil bulk density in cross-section through the wheel track is presented in Fig. 3 (for simplification the points in the convexities from the tread are omitted), and the soil temperature distribution in the chosen observation terms - in Fig. 4 (for simplification the points in the concavities are omitted). Additionally, in both figures data concerning the point outside the track are displayed.

On the cross-section through the tractor

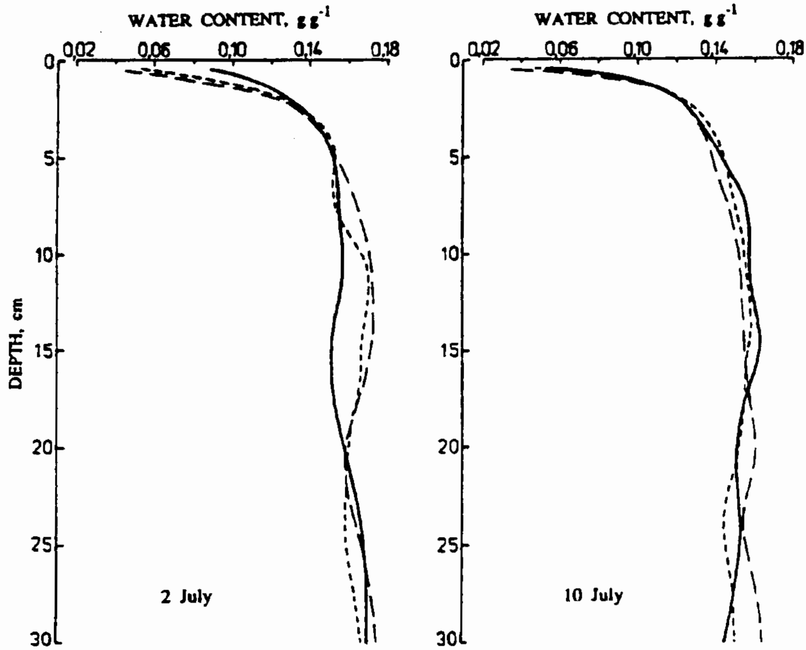

Fig. 2. Distributions with the depth of soil moisture values in the centre of the track (solid line) and two points in the field (0.5 m from the track - dashed line, 1 m from the track - dotted line).

track (Fig. 3) a local increase in soil bulk density, compared to the area around it, can be observed, although it only reached the depth of a few centimeters. The greatest bulk density of soil (over 1.6 Mg m^{-3}) was noted not in the centre of the track, but on one of the edges, at a depth of 9-12 cm, which was probably caused by unequal spatial distribution of the soil bulk density occurring in the arable layer before making the track. The lowest bulk density was recorded on the external borders of the track, which were elevated above the field surface. Considering the distribution of soil bulk density with depth from all measure points it can be stated that the tractor passes caused the local compaction of soil, practically only in the loosened soil layer (0-15 cm). Below that layer the effect of compaction was not significant

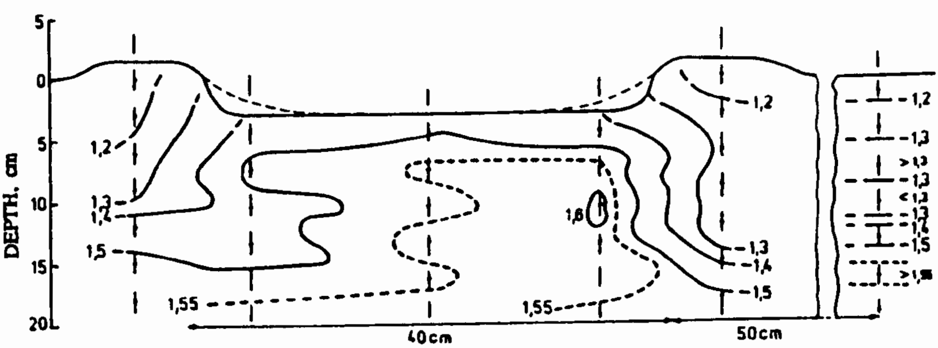

Fig. 3. Distribution of soil bulk density (Mg m^{-3}) in the cross section through the tractor wheel track.

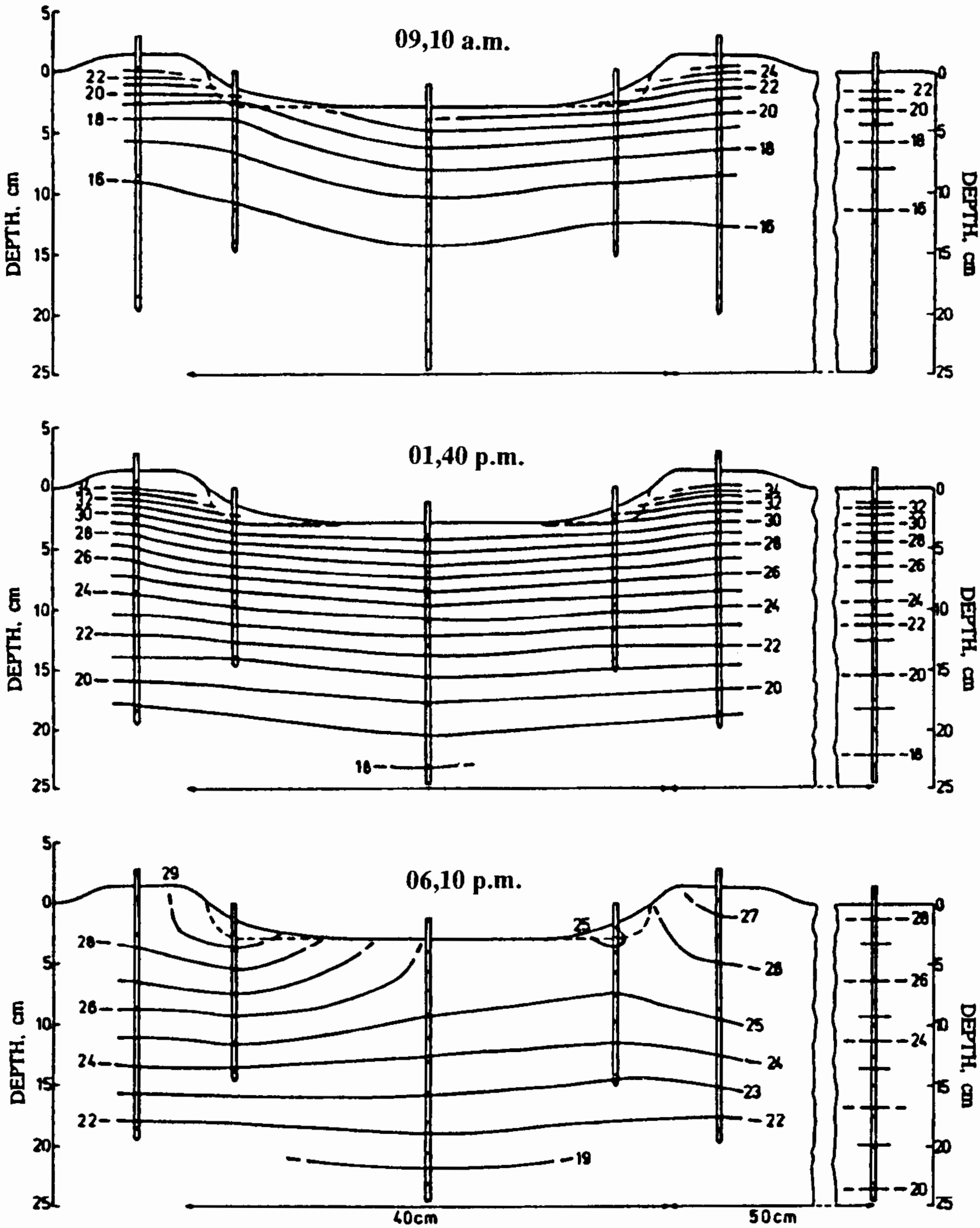

Fig. 4. Distributions of soil temperature (°C) in the cross section of the tractor wheel track on July 10th 1993 at chosen observation terms (09,10 a.m., 01,40 p.m., and 06,10 p.m.).

and the soil bulk density values were within the natural dispersion on the field. Also, the bulk density of compacted topsoil in the track was not higher than the density of deeper soil layers in the field. The results on the thickness of the compacted layer of soil and the values of the change of soil bulk density caused by the tractor passes are similar to the results obtained in the same soil during earlier studies [2,8].

Soil temperature distribution in the track cross-section in the three observational terms (Fig. 4) were chosen as examples. They characterize the temperature differentiation with the depth within the arable layer, related to the natural 24-hour cycle, but also they show the differentiation of the top soil temperature within the track, caused by its exposition. In morning observational terms, a significant differentiation of temperature with depth was only noted in the top layer with the thickness increasing with time, and a lower temperature was observed in the track concavity than on the edges and the outside of the track. At the same time, i.e., when the angle of incidence of sun's rays was low, a higher temperature was observed in the western part of the track than in eastern part. In the early afternoon, when the sun rays were almost parallel to the track direction, the izoterms' course in the cross-section through the track was symmetric on both sides of the track axis. In the top layer, the lowest temperature was observed in the centre of the track, while the highest one was on the edges. The greatest vertical gradients of soil temperature were also observed on the edges, which related to the lowest soil density in those places. In the early evening, the vertical differentiation (gradients) of soil temperature was decreasing, and, at the same time, there was a temperature differentiation again in the top layer, caused by the exposition of particular parts of the track (higher soil temperature in the eastern side than in the western side). During low sun position, the concavity after the tyre tread on the western side of the track was shaded and the concavity on the eastern side was sunshined. As the effect of that, there were great temperature differences in the top layer of soil (clearly shown in Fig. 4).

Generally, the course of izoterms in the cross-sections through the track indicates that during a sunny day, within and close to the track, there is a great differentiation in soil temperature only in the top layer of a few centimeters. Furthemore, the izoterms' course deviated from the horizontal position, mostly visible in the morning and in the evening, indicate that on most of the area of the track section, temperature gradients are directed at different angles, which means that the heat flow in soil is not only vertical, but also oblique.

Comparison of temperature and physical properties of soil in the center and outside of the track

The influence of compaction on soil temperature can also be shown while analysing the data from particular measuring points. In this case, the points in the centre and outside of the track, where there are almost no other influencing factors, other than the physical properties of the soil, are the best for comparison. The surface of the soil in the track (the reference level, from which the temperature measure depths were taken), which was lower than the field surface, can be a minor difficulty here. Taking that into account, the data of the top layer temperature (0-10 cm) was compared according to the real soil surface. However, for deeper layers, the double reference system should be preferred (as in Fig. 5).

As can be seen in Figs. 5a and 7, to a depth of about 12 cm, the temperature of the soil compacted with tractor wheels was almost the whole day (except early morning) lower than in the soil outside the track, while in deeper layers the temperature was higher. The greatest differences in soil temperature in particular depths between the point in the centre and outside of the track were obsverved during the daily maximum. These differences in the top layer were: 3.5 °C at 1 cm depth; 1.4 °C at 4 cm; and about 1 °C at 10 cm. In deeper part of the arable layer the temperature differences were a few tenths of a centigrade. However, the estimation where higher temperature were observed depended on assuming the reference level (see Fig. 5). It is worth noting that in earlier studies [8], but not that detailed, an even greater temperature difference was recorded in the same soil, around 6 °C at the depth of 1 cm between the tract centre and the point outside the tractor wheel track (with similar soil bulk density differentiation - about 0.3 Mg m^{-3}, but

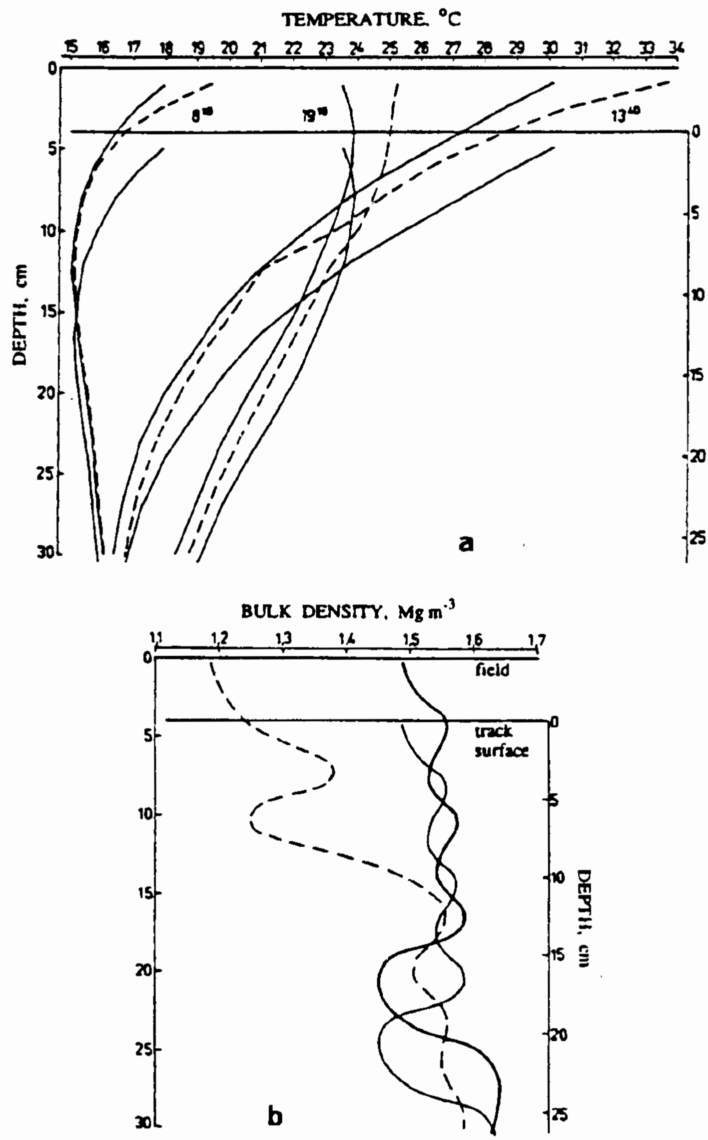

Fig. 5. Distributions with the depth of soil temperature at chosen observation terms (a) and distributions of soil bulk density (b) in the centre of the tractor wheel track (solid line) and outside of the track (dashed line).

with the soil moisture a few per cent lower).

The data of the depths of 1, 4, and 10 cm, included in Table 1, inform that in the centre of the track, smaller changes of temperature during the day and lower mean soil daily temperature compared to the point outside of the track, were observed. At the soil surface (1 cm deep) the 24-hour soil temperature amplitude in the centre of the track, was 4 °C different than in the field, and the mean daily temperature (from the period 05,40 a.m.-07,40 p.m.) 2.5 °C. The data presented above can be treated as the effect of soil bulk density differentiation in the layer from 0 to about 15 cm (Fig. 5b). Soil compaction in the track caused an increase in the values of soil thermal properties (Fig. 6) and, consequently, it slowed down soil warming during the day (and cooling in the evening and at night). It should also be emphasized that the distribution with the depth of

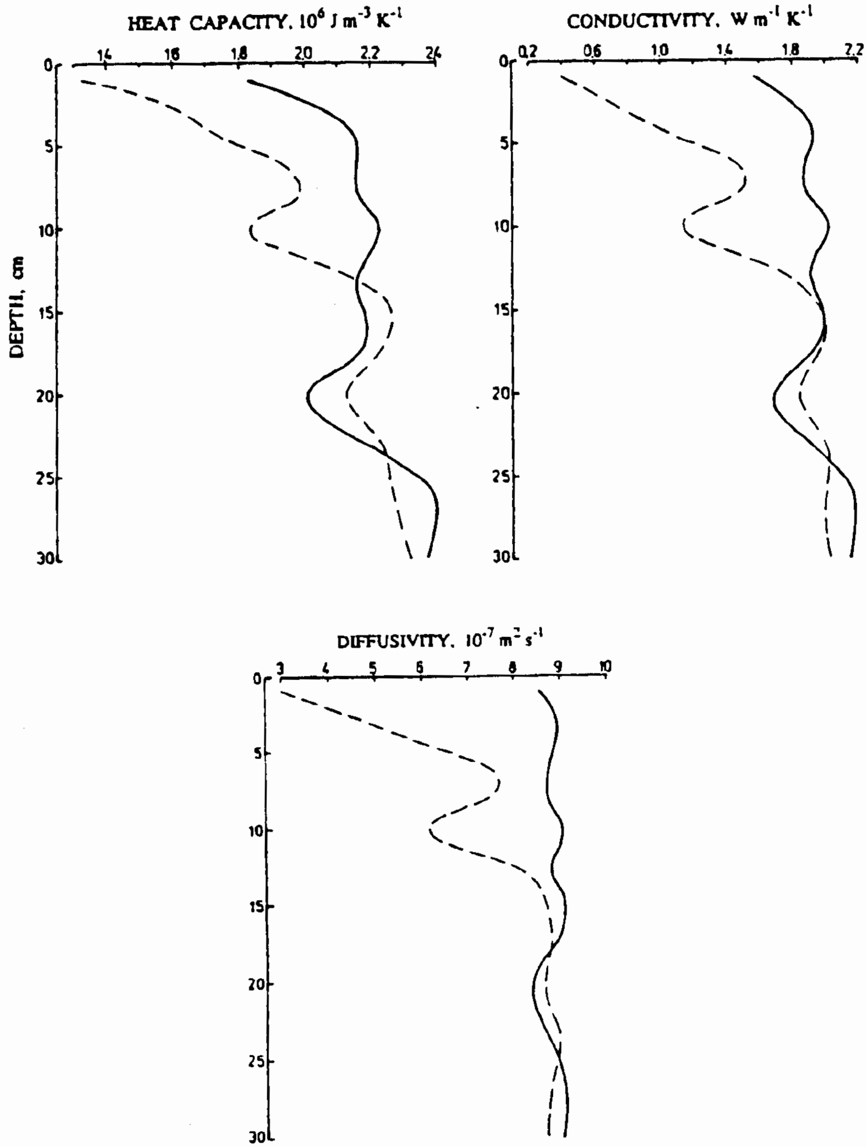

Fig. 6. Distributions with the depth of particular soil thermal properties values in the centre of the track (solid line) and at the point 0.5 m away from the track (dashed line) on July 10, 1993.

all thermal properties of soil in the centre and outside of the track showed a similarity to the distribution of soil bulk density, which was caused by a small difference in soil moisture between the measurement points inside the track and in the field.

The interpretation of soil temperature in the top layer from the points just near the track concavity (i.e., in places of soil uplift around the edges of the track) should, besides soil compaction, also consider soil exposition and microrelief. This approach is evident while analysing the daily temperature courses in Fig. 7. Soil temperature close to the outside edges of the track was, for the most part of the day, the highest among all the measurement points. The greatest temperature differences, in relation to the points outside and in the centre of

Table 1. Soil temperature and bulk density data for individual measuring points inside and outside tractor wheel track

Measuring point	Mean temperature (°C)			Maximum temperature (°C)			T_{max} - T_{min} (°C)			Bulk density ($Mg\ m^{-3}$)	
	Depth (cm)									Layer (cm)	
	1	4	10	1	4	10	1	4	10	0-4	0-10
Outside of the track (8)*	26.5	23.5	20.6	33.7	29.1	25.1	22.1	16.6	11.1	1.20	1.27
Close to the eastern edge (2)	27.0	23.9	20.9	34.6	30.3	26.4	23.3	18.9	13.3	1.18	1.21
Close to the western edge (5)	27.4	24.2	21.3	35.4	30.2	26.0	23.8	18.1	12.9	1.16	1.23
Convexity on the eastern side (4)	25.0	22.9	20.3	33.1	29.6	25.3	21.9	17.5	11.6	1.36	1.36
Concavity on the eastern side (3)	23.2	21.8	19.4	29.5	27.4	23.8	17.4	14.7	9.5	1.46	1.47
Convexity on the western side (7)	24.6	22.7	20.1	31.2	28.1	24.6	19.4	15.9	10.8	1.52	1.56
Concavity on the western side (6)	24.6	22.7	20.2	30.9	27.8	24.4	17.5	14.9	10.3	1.47	1.54
Centre ot the track (1)	24.1	22.5	20.0	30.2	27.8	24.2	18.2	15.2	10.2	1.51	1.53

*Localization of measurement points as shown in Fig. 1.

the track, were: 2.3 and 5.5 °C at 1 cm depth; and 1.8 and 3.1 °C at 4 cm. The highest maximal temperatures, 24-hour amplitudes and mean values for daily periods were also observed here, as well as the lowest soil bulk density (Table 1). However, the observed differences in soil temperature between the points on the western and the eastern side of the track (reaching to 1.6, 2 and 1.2 °C at the depths of 1, 4 and 10 cm, respectively), at similar soil bulk density in both points, can only be explained as the result of exposition, which was different for both points and related to the orientation of the track.

Soil temperature differentiation within the track

The occurrence of the concavities and convexities made by the tyre tread complicates the temperature distribution within the track and makes it difficult to interpret. Generally, at measure points in convexities after the tread, higher maximum temperatures and higher 24-hour soil temperature amplitudes than in the concavities and in the centre of the track were noted, but these relations are not completely the same in the case of mean temperature (Table 1).

To make easier the analysis of soil temperature differentiation within the track and its changes during the day, temperature values measured in the convexities and concavities after the tyre tread and near the edges of the track were presented as deviations from the temperature values in the centre of the track (Fig. 8). It appeared that temperature differentiation within the track concavity (without outside edges) was very big. It changed during the day and was bigger, in this case, on the eastern than the western side of the track. For example, at the depth of 1 cm the differences between the extreme soil temperature values at measure points inside the track were: 2.0 at 06,10 a.m., 4.1 at 10,10 a.m., 3.0 at 01,40 p.m., and 5.1 °C at 06,40 p.m. If we include the ridges around the edges of the track (i.e., if we consider the measure points close to the edges of the track), then the differences between the highest and the lowest temperature values at the depth of 1 cm in the same measure terms were 2.0, 7.4, 7.0, and 5.1 °C (7.9 °C - the greatest difference - was noted at 11,40 a.m.).

As it can be seen in Fig. 8, the soil temperature differentiation within the track decreases with the depth, but is still visible at 10 cm. Interesting also are the much smaller temperature differences observed between the concavity and the convexity of soil on the western than on the eastern side of the track. A reasonable explanation of those differences can be the values of soil bulk density in these points (Table 1). On the eastern side of the track, in the concavity after the tyre tread, there was a greater soil bulk density than in the convexity, which caused, along with the uneqal insolation conditions, such great temperature differences

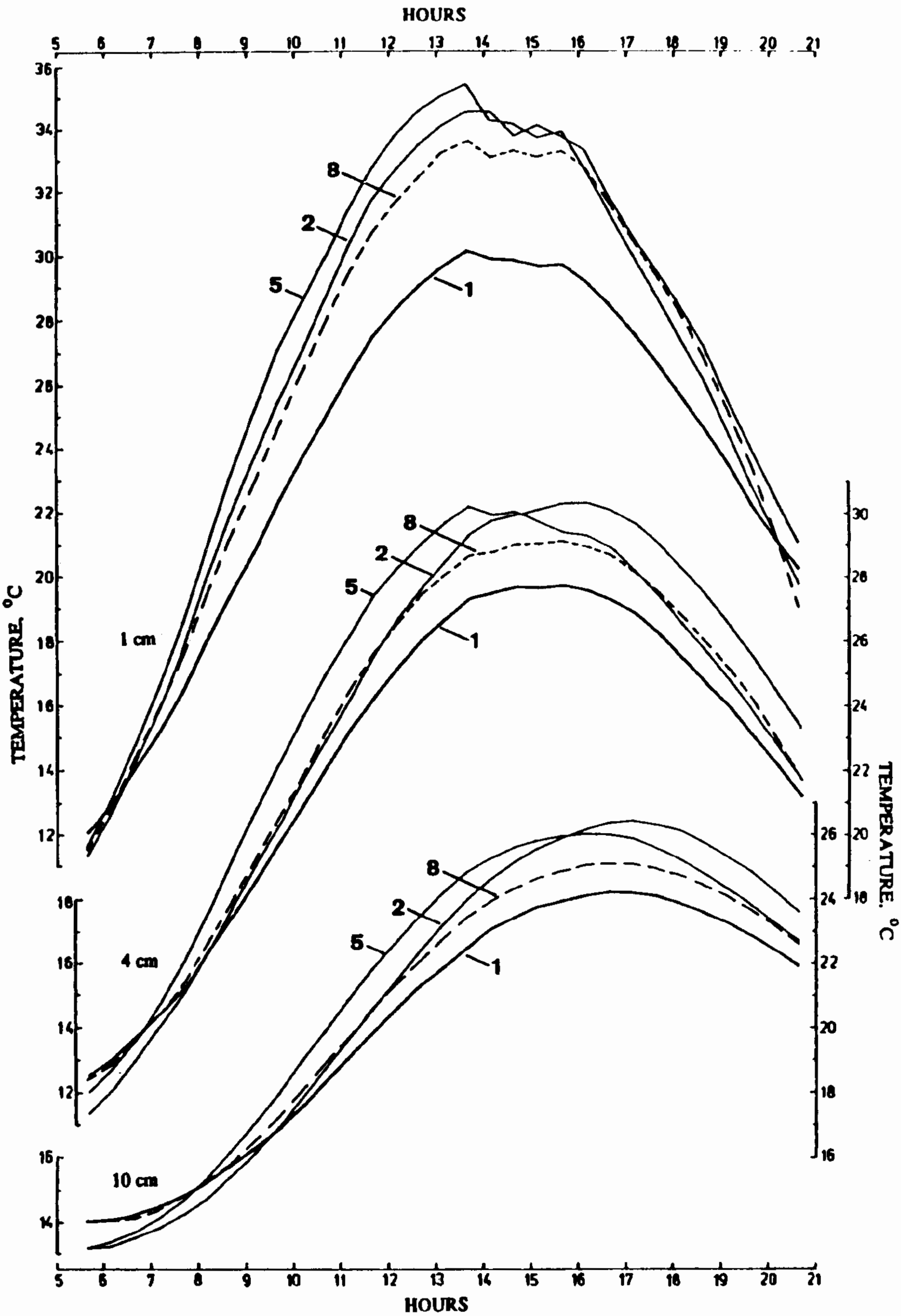

Fig. 7. Daily course of soil temperature at the depth of 1, 4, and 10 cm in the centre of the track (1), near the eastern edge (2) and western edge (5) of the track, and outside of the track (8). Description of points as in Fig.1.

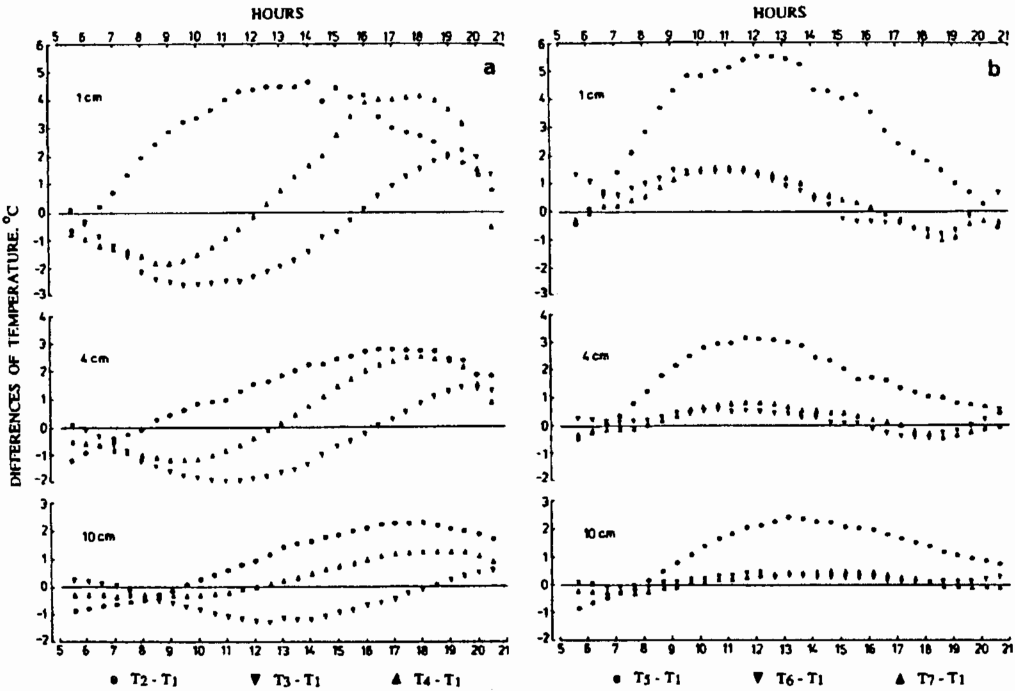

Fig. 8. Daily course of the differences between soil temperature T measured at particular points on the eastern side (a) and on the western side (b) of the track, and soil temperature in the centre of the track on the depth of 1, 4, and 10 cm. Description of points (1-7) as in Fig. 1.

between those elements of the relief. On the western side of the track, soil bulk density in the convexity after the tyre tread was higher than in the concavity, which must have caused the decrease in soil temperature differentiation. Such pattern of soil bulk density was most likely accidental. For any other pattern, but eqally possible, soil temperature differentiation within the track could have been even greater.

It should be emphasized, that the soil temperature distributions and their changes during a sunny summer day, described above concern the track made two months before, directed at the specified angle to the N-S axis, with rounded shape and soil settled around it. For more fresh and differently directed track, other, maybe more significant differentiation of soil temperature would be noted. Therefore, the obtained results should rather be treated as the example of the research of the influence of local soil compaction and microrelief in tractor wheel track on soil temperature.

Differentiation of soil thermal properties in cultivated field with tractor wheel tracks

Finally, a more genaral point of view concerning the physical properties of soil in the tractor wheel track in cultivated field will be presented. In order to do that, the track concavity was treated as a separate part of the field, and the data from the measurement points within the track were treated, as well as the data from the points in the field, as separate groups of data and were averaged. It allowed to calculate the differences in the values of particular thermal properties of soil between the track and the field, and then to calculate the percentage coefficient of variation of these properties changes as the result of the soil compaction in the track. These data, for the two investigated days and 5-cm layers have been presented in Fig. 9. It appeared, that the greatest differences in soil thermal properties between

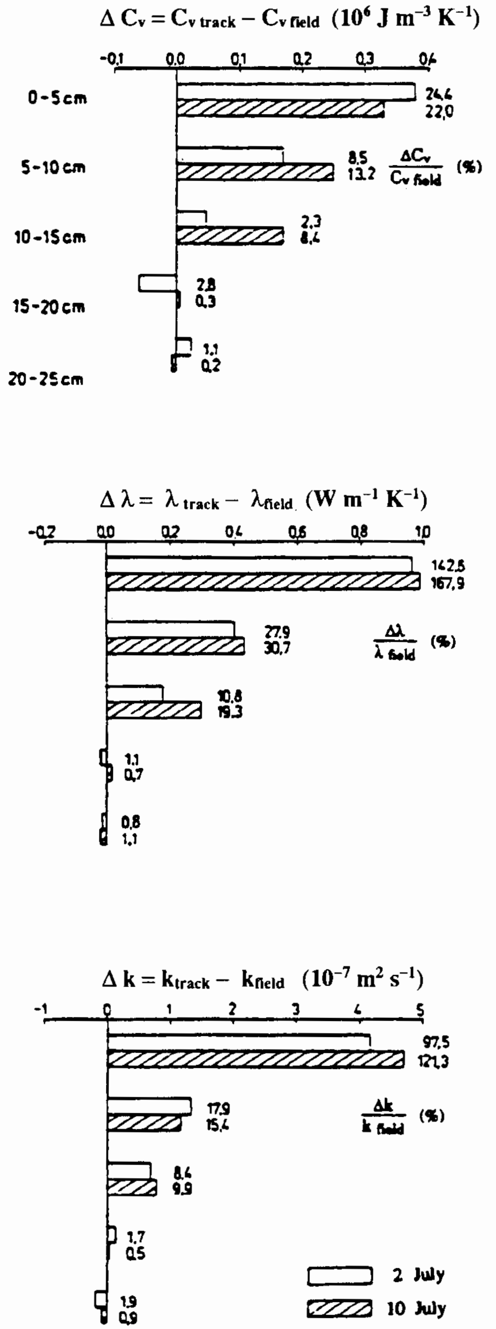

Fig. 9. Differences of the mean for the track and for the surrounding field of the values of volumetric heat capacity (Cv), thermal conductivity (λ) and thermal diffusivity (k) of soil, and the percentage ratio of these differences in relation to the value for the field on July 2nd and 10th, 1993.

the track and the field were observed in the top layer, they were decreasing with the depth, and below 15 cm they were insignificant. The greatest increase in the values caused by the soil compaction was noted in the top layer within the wheel track in the case of thermal conductivity (2.9 times increase), a little smaller - in the thermal diffusivity (2.3 times), and relatively small in volumetric heat capacity (1.2 times).

Because of the most important differentiation in the physical properties of soil in the top layer, the statistic data of the investigated physical properties in the track and in the field in the 0-5 cm layer were listed (Table 2). It should be emphasized, that the maximum bulk density of soil in the field was close to the minimum bulk density in the track. As a consequence, because of the similar relation between the extreme values of soil moisture, also the similar situation was with the minimum and maximum' thermal properties of soil in the track and in the field.

Soil compaction in the track caused the decrease in the variability of all investigated physical properties of soil. In the case of thermal conductivity and diffusivity the coefficient of variability was three times smaller in the track than in the field. In the case of heat capacity this coefficient was not very different and its values were close to the values of the coefficient for soil moisture and bulk density. Such variability of soil thermal properties were caused by the differentiation in soil bulk density and moisture values in the track and in the field, as well as by the character of particular thermal property value's dependency on the bulk density and moisture. Heat capacity depends more on soil moisture, while thermal conductivity and diffusivity of soil, in the observed moisture range, strongly react on both the soil bulk density and the moisture changes. Therefore, even small differences of moisture and bulk density of soil caused such great variability in thermal conductivity and diffusivity.

Besides the higher values of soil bulk density, higher moisture was observed in the track than in the field, especially after rain. Thus, the occurrence of the tractor wheel track

T a b l e 4. Statistical data referring to topsoil (0-5 cm) bulk density, water content and thermal properties for investigated wheel track and field. Number of samples in track and field was 6 and 12, respectively

Statistics	Bulk density ($Mg\ m^{-3}$)		Water content ($m^3\ m^{-3}$)		Heat capacity ($10^6\ J\ m^{-3}\ K^{-1}$)		Conductivity ($W\ m^{-1}\ K^{-1}$)		Diffusivity ($10^{-7}\ m^2\ s^{-1}$)	
	track	field	track	field	track	field	track	field	track	field
					July 2, 1993					
Mean	1.486	1.231	0.190	0.146	1.925	1.547	1.628	0.671	8.431	4.268
Maximum	1.543	1.374	0.198	0.164	2.000	1.730	1.778	1.198	8.888	6.923
Minimum	1.376	1.168	0.176	0.138	1.781	1.464	1.234	0.467	6.930	3.189
Std. dev.	0.060	0.062	0.008	0.009	0.079	0.083	0.201	0.253	0.746	1.341
Coef. var.	4.061	5.018	4.172	5.950	4.111	5.373	12.336	37.738	8.848	31.419
					July 10, 1993					
Mean			0.169	0.137	1.838	1.506	1.570	0.586	8.514	3.847
Maximum			0.176	0.158	1.908	1.705	1.754	1.181	9.192	6.926
Minimum	As above		0.157	0.131	1.702	1.439	1.182	0.452	6.947	3.143
Std. dev.			0.007	0.007	0.074	0.075	0.213	0.201	0.850	1.040
Coef. var.			3.980	5.370	4.025	4.972	13.552	34.205	9.988	27.027

causes the increase in the differentiation of physical properties of soil in a cultivated field not only as the result of the local soil compaction but also through microrelief.

CONCLUSIONS

The tractor wheels caused local soil compaction only in the loosened layer - to a depth of 15 cm. Below this level the effect of compaction was not visible, and the bulk density values were in the range of the natural dispersion in the field.

As a result of soil compaction in the track the values of particular thermal properties of soil increased, especially in the top, several centimeter thick layer (2.9 times increase in the case of thermal conductivity, 2.3 times in thermal diffusivity, 1.2 times in heat capacity). The differences in values of soil thermal properties between the track and the surroundings decreased with depth, and below 15 cm they were very small.

Significant differentiation in the values of bulk density, thermal properties, and temperature of soil between the tractor wheel track and the surroundings, recorded almost two months after the track was made, shows the long lasting consequences of local soil compaction in cultivated fields.

Generally, during a sunny day in the spring-summer period, in the track concavity left by the tractor wheels, lower soil temperature in the top layer and smaller amplitude of its changes than in the surrounding cultivated field were observed. This phenomenon is the result of the local soil compaction, which leads to increase in the values of soil thermal properties and slows down the warming of soil during the day.

The temperature differences between the track and the field are, by nature, the greatest near the soil surface, decrease with the depth, and show a distinct daily course. In the described case of the track and the sunny summer day, the soil temperature difference noted at the depth of 1 cm, measured in the centre and outside of the track, reached, in the mean value for the daily period 2.5 °C, and for the maximum value 3.5 °C (these data can be treated as the only effect of the differentiation of the physical properties of soil).

The occurrence of the soil surface microrelief elements within the track (convexities and concavities after the tyre tread, uplifts at the external edges of the track) causes considerable temperature differentiation in the top layer of soil. A difference of 8 °C in extreme values of soil temperature at 1 cm depth within the investigated track was observed as the joint effect of the differences in soil thermal properties and insolation between the particular elements of microrelief.

The orientation of the track determines the exposition of all parts, but especially of the inside walls of the track. In this case of the track direction (NE-SW) the temperature effects of insolation-shadowing of soil within the track were most significant at the low position of sun over the horizon before evening.

During a sunny day, soil temperature gradients in the track are directed at different angle, so the heat flow in the soil is not only vertical, but also slanted. This sets some specific conditions while modelling soil temperature in cultivated field, where local disturbances in spatial distribution of soil physical properties caused by the wheels of agricultural machines are often evident.

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TEMPERATURA I WŁAŚCIWOŚCI CIEPLNE GLEBY W ŚLADZIE PRZEJAZDU KÓŁ TRAKTORA JAKO EFEKT LOKALNEGO ZAGĘSZCZENIA GLEBY I MIKRORELIEFU

Celem pracy było zbadanie wpływu lokalnego zagęszczenia gleby i mikroreliefu na rozkład temperatury gleby w obrębie śladu przejazdu kół traktora oraz określenie zróżnicowania wartości właściwości cieplnych gleby na polu uprawnym bez roślin gdy taki ślad występuje. Materiał wyjściowy stanowiły wyniki pomiarów temperatury gleby w 8 punktach przekroju poprzecznego przez ślad 2-krotnego przejazdu traktora oraz wyniki pomiarów gęstości i wilgotności gleby w śladzie i poza śladem, przeprowadzonych po 2 miesiącach od powstania śladu na lessopodobnej glebie pylastej. Właściwości cieplne określono metodami obliczeniowymi w oparciu o zmierzone wartości gęstości i wilgotności gleby w warstwie ornej. Największe różnice każdej z właściwości cieplnych między glebą w śladzie i jego otoczeniu stwierdzono w warstwie przypowierzchniowej, odpowiednio do największych różnic w rozkładach pionowych gęstości gleby. W dolnej części warstwy ornej wartości poszczególnych właściwości fizycznych gleby były zbliżone i mieściły się w naturalnym rozrzucie na polu. Odtworzono i przeanalizowano rozkłady gęstości i temperatury gleby w przekroju poprzecznym przez ślad oraz przebiegi dzienne temperatury gleby w poszczególnych punktach pomiarowych. Największa różnica temperatury gleby jaką zaobserwowano około południa podczas słonecznego dnia letniego pomiędzy punktami w śladzie wynosiła 8 °C (na głębokości 1 cm). Wykazany został wpływ właściwości fizycznych gleby jak i wpływ mikroreliefu powierzchni i ukierunkowania śladu względem stron świata na zróżnicowanie temperatury gleby w obrębie śladu w różnych porach dnia.

S ł o w a k l u c z o w e: zagęszczenie gleby, temperatura, właściwości cieplne, mikrorelief, ślad kół traktora.