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Research Article

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Effect of different types of soil tillage for sunflower on some soil physical characteristics. Part II: bulk density and soil temperature

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Abstract: The investigation was carried out during 2014–2016 in the land of General Toshevo, the South Dobrudzha region of Bulgaria on slightly leached chernozem soil type. The effect of the types of soil tillage for sunflower given bellow was followed: ploughing at 24–26 cm, chisel-plough at 24–26 cm, disking with disk harrow at 10–20 cm and direct sowing (no-tillage) on the bulk density, the moisture content and the temperature of soil. The additional soil tilths of the areas subjected to ploughing, chisel-ploughing and disking with disc harrow included double spring pre-sowing cultivation with harrowing. To destroy the emerging weeds in the variant with direct sowing, a total herbicide was applied. The investigated physical parameters of soil were followed during three main stages of sunflower development: emergence, flowering and technical maturity. The bulk density of soil was determined by soil samples taken from the 0–10, 10–20 and 20–30 cm layers. The soil temperature was read at 800, 1200 and 1600 h to depth 2, 5, 10, 15, 20 and 25 cm with classical soil thermometer. For evaluation of the results dispersion and regression analyses were used. In the slightly leached chernozem soil type, the conventional ploughing leads to lower bulk density in the cultivated soil profile. Under minimal tillage, slight increase of bulk density of the layer underlying the cultivated one was observed over time. The bulk density under tillage without turning of the soil layer and no-tillage was changed and

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formed primarily under the influence of physical and climatic factors, and under minimal tillage – under the cultivated layer. Under all investigated types of soil tillage, bulk density increased down the soil profile. Replacing ploughing with tillage without turning of the soil layer, minimal and no-tillage lead to decrease of soil temperature. The most significant differences were observed in the 0–10 layer, which, on its part, conditioned accumulation and transfer of thermal energy along the soil profile. The soil temperature decreased with the reduction of the number and depth of the soil tillage operations. The temperature amplitudes between the surface layer and the underlying soil horizons in the areas with ploughing, chisel ploughing minimal and no-tillage were lower. The results concerning the values of the investigated physical properties of soil under different types of soil tillage were statistically significant at different levels of P.

Keywords: bulk density; soil temperature; soil tillage; sunflower.

Introduction

The focus on the role of soil's bulk density in the recent years is justified by the concepts of minimal tillage and direct sowing in the new systems developed for soil tillage under conditions of chemicalized agriculture. Multiple studies have been conducted to determine the marginal values of these parameters depending on the crop and the soil and climate conditions. The increased bulk density of soil causes changes in the structure of its pores, greater hardiness and lower permeability.

The negative effect of bulk density on plants is related to lower porosity (Brussaard and Faassen 1994; Whalley et al. 1995), inhibited growth and development of roots (Croser et al. 2000; Lecompte et al. 2003; Wang et al. 2015; Yankov and Drumeva 2017), lower efficiency of soil water utilization and nutrients uptake (Çelik 2011; Nosalewicz and Lipiec 2014; Vocanson et al. 2006; Watson and Kelsey 2006), lower yields from the agricultural crops (Andrew et al. 2011; Whalley et al. 2008). According to Smith (1988), at bulk density over 1.6 g/cm^3, root growth is restricted and the flow of water in soil is impeded. Sometimes the higher bulk density of soil is desirable since it can facilitate better contact of the soil particles with seeds thus conditioning the uniform emergence and development of plants (Radford and Nielsen 1985).

The majority of the investigations confirm that the exclusion of tillage leads to higher bulk density of soil, especially evident in the surface layer (Dam et al. 2005; Fabrizzi et al. 2005; Hazarika et al. 2009; Tebrügge and Düring 1999; Zibilske et al. 2002). The soil is capable of recovering to some extent from being too dense under the influence of biological and physical processes, which occur in it (Logsdon and

Karlen 2004). Over time, when left to rest, soil tends towards a certain type of bulk density (Moraru and Rusu 2012), the so called equilibrium density. The values of this parameter are different for the individual soil types. The physical equilibrium of soil may be disturbed by short-term events such as intensive traffic of agricultural machines in the field, changeable climatic conditions, alterations in the crop rotation (Moreira et al. 2016). When using disking tools for soil tillage as an alternative to conventional ploughing, it has been found out that bulk density increases with the increase of the tilt angle of the discs and with the time after the performance of the soil tillage (Gbadamosi 2013; Osman et al. 2011). The use of shallow soil tillage types also increases the bulk density down the soil profile (Nargish et al. 2014).

The effect of the more intensive types of tillage (deep main ploughing, chisel plough) is expressed in decrease of the bulk density of soil (Gbadamosi 2013; Heidarpur et al. 2011). The lower values of this parameter are probably due also to the incorporation by ploughing of the cultural plants residues on the soil surface (Bhattacharyya et al. 2006). It should be also noted that the long-term ploughing at the same depth at improper soil moisture content is a prerequisite for the formation of plough pan, which deteriorates the physical properties of the soil (Bertolino et al. 2010).

The thermal conditions of the soil affect some chemical and biological processes, which have impact on the development of the plants and the quantity and quality of the plant produce. The increase of soil temperature within a certain range shortens the time to seed germination, accelerates the microbiological activity and the growth and activity of the plant roots. The thermal regime of soil is related to the relief of its surface and the flow of thermal energy. The flow of thermal energy depends on the meteorological conditions, the availability of plant or snow cover and the physical properties of soil. The amount of thermal energy absorbed in soil is related to its thermal conductivity, its thermal capacity and vertical thermal gradient, which are dependent on the water content in the soil profile (Dalmago et al. 2004).

According to Moraru and Rusu (2012), the use of minimal and no tillage leads to decrease of the temperature amplitude in the upper soil layer (15 cm) and increase of the soil temperature with 0.5–2.2 °C. Dalmago et al. (2004) have found out that at the beginning of the plant development, the soil temperatures under the conventional soil tillage system are higher than under direct sowing. With the crop development, higher temperatures are read under no-tillage related to the absorption of solar radiation from leaves.

Other authors point out that in comparison to the cultivated areas, the uncultivated ones are characterized with considerably lower temperature (Fabrizzi et al. 2005; Kühling et al. 2017; Toshitsugu and Haruhiko 2002). The lower temperatures on the soil surface caused by the accumulated plant residues from the grown crops (Al-Darby and Lowery 1987; Gupta et al. 1988) can have unfavorable effect on the emergence and development of the plants under direct sowing in the mid-latitudes (Munawar et al. 1990).

The aim of this investigation was to study the effect of different ways of soil tillage for growing of sunflower on the bulk density and the temperature of the slightly leached chernozem soils in the South Dobrudzha region of Bulgaria.

Materials and methods

Soil and climatic conditions

The investigation was carried out during 2014–2016 in the area of General Toshevo, South Dobrudzha region of Bulgaria.

The soils are represented by slightly leached chernozems (Yolevsky et al. 1959). These are heavy sandy loamy soils along the entire profile, which have favorable water and air regime. The bulk density characterizes them as soils of loose structure, without the presence of dense horizons.

The mean annual temperature in the region is 10.6 °C (–0.3 °C for January, and 21.3 °C for July), and the mean annual precipitation sum is 518.3 mm. The maximum rainfalls are during May–June, and the minimum is during August–September.

The analysis of the meteorological data shows that the investigation was carried out in years with variable climatic conditions (Figure 1). The mean diurnal air temperature in April, the month

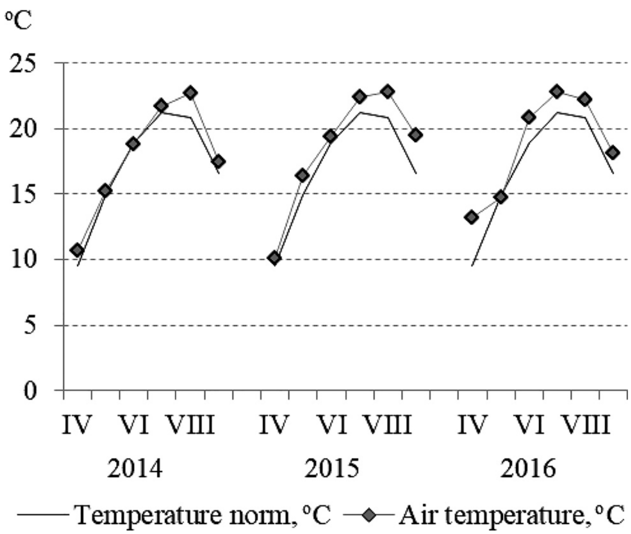


Figure 1: Air temperature during the vegetation period of 2014–2016 (°C).

in which the sunflower plants emerge and start their development, was higher than normal in 2014 and 2016. During the same period of 2015, the air temperature was close to the climatic norm. The month of July, when sunflower is in mass flowering, was warmer than the long-term mean diurnal air temperature for this month in 2015 and 2016. During the same period, the air temperature in 2014 was close to the norm. September, the month in which technical maturity of sunflower occurs and when it is harvested under the conditions of the South Dobrudzha region, was warmer than normal in all three years of the investigation. In parallel with this, the mean diurnal air temperature during the entire period of vegetative growth of sunflower was higher than the average long-term value – with 3.5% in 2014, with 7.0% in 2015 and with 8.7% in 2016.

Field experiment

The investigation included for types of soil tillage for sunflower – ploughing at 24–26 cm (CT), chisel plough at 24–26 cm (CC), disking with disk harrow at 10–12 cm (DD) and no-tillage (NT). The variants were designed according to the long plot method in eight replications, the size of the trial plot being 72 m^2. Sunflower was grown after previous crop wheat.

The soil tillage for sunflower was done early, during August. The additional soil tillage of the areas cultivated with ploughing, chisel-plough and disking included double spring pre-sowing cultivation with harrowing. To destroy the emerging weeds in the variant with no-tillage, a total herbicide was applied once or twice. In the cases with heavy infestation with weeds, spraying in the autumn and in spring, prior to sowing, was done. Only a single pre-sowing spraying was applied when there were no weeds.

Soil tillage for wheat included double disking with disk harrows at 10–12 cm after harvesting of sunflower.

Sunflower was planted at sowing norm 65 000 plants/ha. The weeds emerging during the vegetative growth of the crop were controlled in all tested variants by using the appropriate herbicide.

Bulk density

The bulk density of soil was determined by soil samples taken from layers 0–10, 10–20 and 20–30 cm of each replication from plots without plants, by using 100 cm^3 rings. The samples were taken at three different stages of sunflower vegetation – emergence flowering stage and technical maturity. The soil samples were weighed and dried at 105 ^{o}C to constant weight, then they were weighed again to determine the bulk density.

Soil temperature

The mean daily temperature of soil was measured at depth 2, 5, 10, 15, 20 and 25 cm at the same sunflower vegetation phases as at the evaluation of bulk density. Reading was done on plantless plots using stationary soil thermometers placed before sowing of sunflower. Observations were made at 08:00, 12:00 and 16:00 h.

Statistical analysis

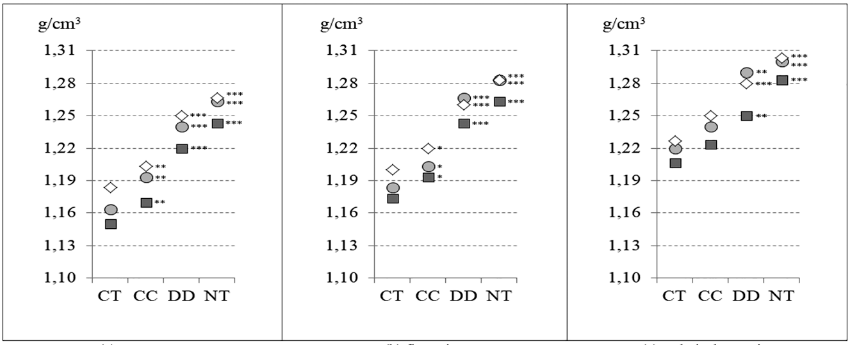
Dispersion and regression analyses were carried out to follow the statistical significance in the differences of the values of the investigated physical properties of soil under different types of soil tillage when growing sunflower and of the interaction of some of them with the meteorological conditions over the years of the investigation.

Results and discussion

Bulk density

The bulk density of soil, as an indicator of the quality of its preparation, is often one of the most frequently followed parameters in the soil experiments (Rasmussen 1999).

At stage emergence of sunflower, in the surface layer, the bulk density under ploughing was lowest – 1.15 g/cm^3, followed by chisel plough (Figure 2a). According to Celik et al. (2013), the low value of the bulk density in the 0–5 cm is an indicator for the quality preparation of the seed bed allowing grater amount of water to permeate the soil and a faster growth of the sunflower plants. Under disking and no-tillage, the bulk density of soil reached 1.22–1.24 g/cm^3. In the 10–20 and 20–30 cm layers, the observed parameter increased under all investigated types of soil tillage. Lowest values of bulk density were registered in the



(a) emergence			(b) flowering			(c) technical maturity		
$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$	$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$	$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$
0.012	0.017	0.038	0.016	0.025	0.040	0.023	0.035	0.056

*, **, *** – Significance of effects and variations at P levels 0.05, 0.01 and 0.001, respectively

■ 0-10 cm ● 10-20 cm ◇ 20-30 cm

Figure 2: Bulk density of soil during main stages of sunflower vegetative growth under different types of tillage (g/cm^3).

intensively cultivated areas. The results were statistically significant at different levels of P.

Due to the exclusion of the inter-row tillage during the vegetative growth of sunflower and the natural subsidence of soil, at flowering stage the bulk density increased in all studied variants and depths (Figure 2b). Only in the areas with disking with disk harrow higher density was found in the 10–20 cm layer in comparison to depth 20–30 cm, probably caused by the work of the soil tillage parts of this tool. The tendency toward higher values of soil bulk density with the minimalizing and exclusion of soil tillage remained valid. The results were statistically significant at different levels of P.

At technical maturity of sunflower, with the decrease of the number of tilths, the bulk density of soil in the surface layer (0–10 cm) increased, reaching the highest value under direct sowing (Figure 2c). Down the soil profile, with the reduction and exclusion of the tilths, higher bulk density was also primarily determined. At the end of the vegetative growth of plants, when left to rest, the soil tended towards its natural structure and balanced density. Under shallow main tillage performed with disking harrow, greater differentiation was observed, expressed in increasing bulk density from the surface to the underlying layer (10–20 cm), then decreasing further down the soil profile (20–30 cm). The results were statistically significant at different levels of P.

The lower density in the cultivated soil layer under ploughing, for the duration of the entire vegetative growth of sunflower, besides to the more intensive loosening of soil after this type of soil tillage, was also due to the incorporation of the plant residues from the previous crop (Bhattacharyya et al. 2006; Gangwar et al. 2006). Other authors also point out that in comparison to other types of tillage, ploughing causes lower bulk density of soil (Çelik 2011; Fabrizzi et al. 2005; Gbadamosi 2013; Heidarpur et al. 2011; Mohammadi et al. 2009). Under annual disking with disk harrow, the dustiness of soil caused by the working parts of this tool lead to higher density in the soil surface layer and in the layer underlying the cultivated one. Due to the exclusion of the annual turning of the soil layers, in chisel plough and no-tillage the values of the bulk density in the surface layer were determined by the action of the climatic factors: rainfalls, temperature, freezing, defrost, etc., which are typical for the moderate climate; they were also determined by the type and number of the passages of the agricultural machines used for cultivation and harvesting of the agricultural crops (Fabrizzi et al. 2005). The higher bulk density in the lower soil horizons under all types of tillage used as an alternative to ploughing, where there was no incorporation of plant residues, was strongly dependent on: the conditions for restructuring of the soil particles when soil was left to rest; the total porosity formed by the micro channels and channels along the root fibers and the roots, as well as the passages formed by the activity of

Table 1: Results from the dispersion analysis on the effect of the investigated factors on bulk density of soil.

Source	Df	Mean square	F	Sig.
Year conditions (A)	2	5.278	0.050	0.951
Crop stage (B)	2	0.054	52.027	0.000
Soil tillage (C)	3	0.129	123.231	0.000
Depth of layer (D)	2	0.020	18.688	0.000
A * B	4	0.000	0.262	0.902
A * C	6	0.001	1.176	0.320
A * D	4	0.001	1.018	0.399
B * C	6	0.001	0.629	0.707
B * D	4	0.000	0.285	0.887
C * D	6	0.001	0.507	0.803
A * B * C	12	0.000	0.405	0.961
A * B * D	8	0.001	0.596	0.781
A * C * D	12	0.001	0.689	0.761
B * C * D	12	0.000	0.142	1.000
A * B * C * D	24	0.001	0.965	0.514

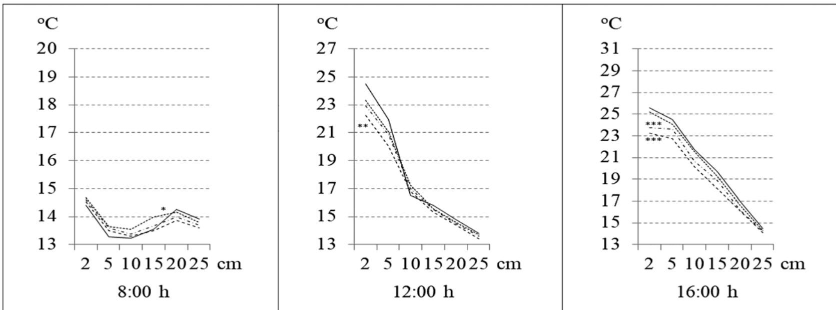
worms. Jin et al. (2011) point out that after using direct sowing for 11 years, the bulk density of soil in the 0–10 and 10–20 cm layers decreased in the areas without tillage as compared to the ploughed areas. In the underlying layer (20–30 cm), the differences in the soil bulk density under these types of tillage were insignificant.

The results from the multi-factor dispersion analysis showed that the factors “crop stage”, the applied “soil tillage” and “depth of the layer” were with significant effect on the values of the bulk density of soil at P = 0.001 (Table 1).

Soil tillage had the highest effect on the bulk density of soil (64.39%), followed by crop stage (18.14%) and depth of the soil layer (6.49%). The factor year conditions did not have a statistically significant effect on the parameters of the investigated trait. Heidarpur et al. (2011) have also pointed out that in spite of the difference in the amount of rainfalls and their distribution over years, during their experiment this factor of the environment did not influence the value of the bulk density of soil. The combined effect of the factors was not significant.

Soil temperature

Under the conditions of higher mean daily air temperatures during the spring and summer season as compared to the long-term ones, at emergence and flowering stage of sunflower, in the early hours of the day, the warming of the surface soil

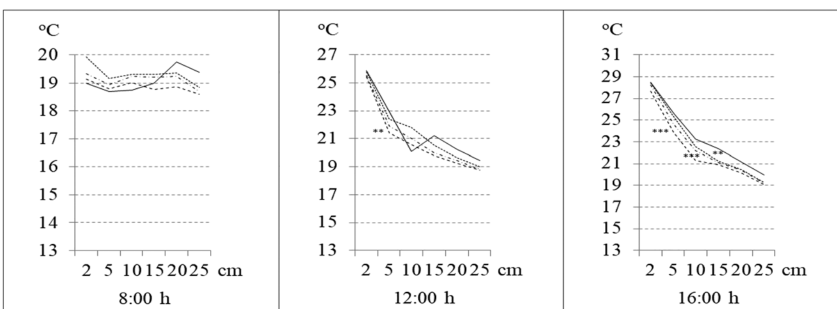


$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$	$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$	$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$
0.159	0.220	0.304	0.544	0.752	1.039	0.427	0.590	0.815

*, **, *** – Significance of effects and variations at P levels 0.05, 0.01 and 0.001, respectively

—— CT ┄┄ CC -·-·- DD ------- NT

Figure 3: Soil temperature under the investigated types of soil tillage, averaged for the investigated period, at emergence of sunflower (°C).



$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$	$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$	$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$
0.334	0.462	0.638	0.520	0.718	0.993	0.338	0.467	0.642

*, **, *** – Significance of effects and variations at P levels 0.05, 0.01 and 0.001, respectively

—— CT ┄┄ CC -·-·- DD ------- NT

Figure 4: Soil temperature under the investigated soil tillage types, averaged for the period of study, at flowering stage of sunflower (°C).

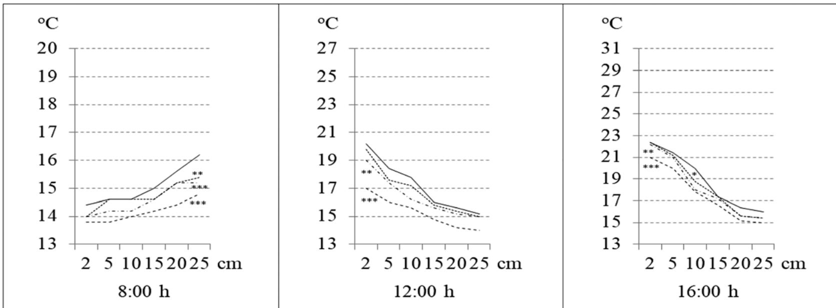
layers (2–10 cm) was lower under ploughing (Figure 3 and 4). This was probably due to the greater amount of air locked between the soil particles and pores, which impeded the penetration of the thermal waves down the soil profile. In the areas with chisel plough, disking and direct sowing, higher temperatures were read. Under these types of tillage, the warming of the soil decreased from minimal tillage to no-tillage. At depth 15 cm, temperature was lowest under direct sowing. In the underlying horizons (20–25 cm), the differences in the warming of the soil decreased under the different types of tillage. Higher temperatures were registered under ploughing. The higher bulk density of soil down the soil profile under tillage without turning of the soil layer, minimal and no-tillage probably determined the greater thermal diffusion during the evening hours up and down the soil profile (Fabrizzi et al. 2005).

In the mid-day hours, a tendency was observed toward increase of temperature in the investigated layers under ploughing. With reduction of the soil tillage, the warming also decreased and was lowest under constant direct sowing. Other authors also reported higher soil temperatures under conventional ploughing in comparison to areas with no-tillage (Dalmago et al. 2004; Fabrizzi et al. 2005; Moraru and Rusu 2012). The reason for this was on the one hand the grater soil surface of the ploughed areas (Jin et al. 2011), which was in contact with air and which absorbed the solar radiation. On the other hand, the plant residues from the previous crop were left on the areas cultivated with chisel plough, disking with disk harrow and with no-tillage. A part of them functioned as mulch and decreased the amount of solar energy reaching the soil (Zhang et al. 2009). As a result from these types of tillage, the increase of temperature in the soil layers in the hotter hours of the day was limited.

In the afternoon hours, under all systems of soil tillage, warming down the soil profile was observed. The temperature was highest under annual ploughing. With the reduction of the tillage, the temperature amplitudes between the surface layer and the underlying soil horizons decreased. The greater temperature amplitude after ploughing was a result from the higher maximal temperatures measured. The differences in the soil temperature between the different types of soil tillage, at different hours of the day and in different layers registered at stages emergence and flowering of sunflower were significant at different levels of P. Having in mind the results, it can be assumed that in very warm years, the tillage without turning of the soil layer, and the minimal and no-tillage can sustain higher stability of the temperature regime of the soil. This is very important for a number of processes in the soil-plant system. Under conditions of high mean daily air temperatures, the lower soil temperatures contribute to the better development and higher activity of the roots during the vegetative growth of some agricultural crops – maize, soybean, etc (Lal 1974).

At the beginning of autumn, at stage technical maturity of sunflower, the mean daily air temperatures decreased and the diurnal temperature increased. In the early hours of the day, with the reduction of the number and depth of the soil tillage operations, decrease of the soil temperature was registered at all observed depths (Figure 5).

This tendency remained valid at the mid-day hours as well. There were greater temperature differences in the surface 5 cm layer. The temperature of the slightly leached chernozem soil under chisel plough, disking with disk harrow and direct sowing remained lower than the check variant. Probably due to the higher bulk density of the soil after these types of tillage, with the decrease of the air



$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$	$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$	$LCD_{0.05}$	$LCD_{0.01}$	$LCD_{0.001}$
0.224	0.310	0.429	0.488	0.675	0.933	0.411	0.568	0.785

*, **, *** – Significance of effects and variations at P levels 0.05, 0.01 and 0.001, respectively

—— CT ········ CC ·-·-· DD ------- NT

Figure 5: Soil temperature under the investigated types of soil tillage, averaged for the period of investigation, at stage technical maturity of sunflower (°C).

temperatures in the evening hours, the thermal losses in the soil profile were higher in comparison to ploughing. Therefore, greater amounts of solar radiation were necessary in the morning and mid-day hours for their warming.

In the afternoon hours, the differences in the soil temperature under the different types of tillage decreased. Temperature remained highest in the areas with ploughing. With the reduction of the soil tillage operations, decrease of the soil temperature was determined at all observed depths. The larger contact surface of the soil with the air under ploughing probably favored the better absorption of the solar radiation. The lower bulk density down the soil profile under this type of tillage conditioned the availability of more air locked in between the soil particles and pores. As a good insulator, air decreased the thermal diffusion along the soil profile. The statistical results on the soil temperature in the different hours of the day and in different soil layers read at stage technical maturity of sunflower were significant at different levels of P.

The results from the miltifactor dispersion analysis showed that all investigated factors had significant effect on the temperature of soil at P = 0.001 (Table 2). Their combined double interaction was significant at P = 0.001 only for the combination "crop stage x depth of layer". The triple combinations and the combined quadruple interaction of the investigated factors did not have a statistically significant effect.

Table 2: Results from the dispersion analysis on the effect of the investigated factors on soil temperature.

Source	Df	Mean square	F	Sig.
Year conditions (A)	2	63.918	160.339	0.000
Crop stage (B)	2	1357.474	3.405	0.000
Soil tillage (C)	3	28.842	72.351	0.000
Depth of layer (D)	5	395.480	992.068	0.000
A * B	4	0.019	0.048	0.996
A * C	6	0.129	0.323	0.925
A * D	10	0.128	0.321	0.976
B * C	6	1.172	2.939	0.008
B * D	10	20.087	50.387	0.000
C * D	15	0.469	1.178	0.286
A * B * C	12	0.222	0.556	0.877
A * B * D	20	0.102	0.256	1.000
A * C * D	30	0.277	0.695	0.888
B * C * D	30	0.374	0.938	0.563
A * B * C * D	60	0.157	0.394	1.000

Table 3: Regression models for the correlation between the investigated physical characteristics of soil in the cultivated soil layer, under different types of tillage for sunflower.

General regression model	$Y = a + b_1x_1 + b_2x_2 + b_3x_3$
Content of productive moisture in soil	
Ploughing	$Y = 1.133 + 19.771x_1 + 27.496x_2 + 35.122x_3$
Chisel-plough	$Y = 1.610 + 18.215x_1 + 26.131x_2 + 37.576x_3$
Disking with disk harrow	$Y = 0.782 + 13.993x_1 + 24.987x_2 + 33.269x_3$
No-tillage	$Y = 1.171 + 17.329x_1 + 22.896x_2 + 29.336x_3$
Soil temperature	
Ploughing	$Y = 1.431 + 5.693x_1 + 4.327x_2 + 3.624x_3$
Chisel-plough	$Y = 1.411 + 5.825x_1 + 4.102x_2 + 3.114x_3$
Disking with disk harrow	$Y = 1.561 + 6.781x_1 + 3.859x_2 + 1.505x_3$
No-tillage	$Y = 1.556 + 5.053x_1 + 3.999x_2 + 2.774x_3$

x_1 – bulk density in 0–10 cm layer; x_2 – bulk density in 10–20 cm layer; x_3 – bulk density in 20–30 cm layer

Model of the relationship between the investigated physical characteristics of soil for the cultivated soil layer

To determine the correlation between the bulk density of soil and the rest of the investigated physical parameters – soil moisture content and temperature,

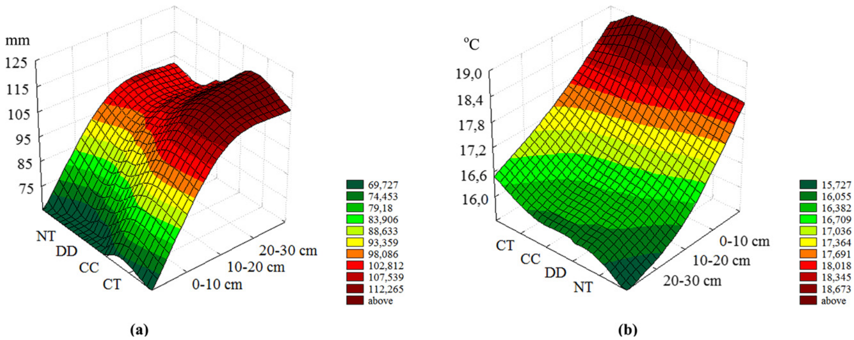


Figure 6: Graphic representation of the regression model of the traits productive moisture content (a) and soil temperature (b).

regression analysis was applied to the cultivated soil layer under different types of soil tillage. The soil moisture content data used for the regression analysis were represented in part one of current investigation. Based on the established models (Table 3) and the obtained experimental data, a graphical model of the respective equation was constructed (Figure 6). With b_i were designated the respective weight coefficients, with b_1 – the bulk density in the 0–10 cm layer, with b_2 – the bulk density in the 10–20 cm layer, and with b_3 – the bulk density in the 20–30 cm layer.

On the basis of the applied analysis it was found out that under all investigated types of tillage, the bulk density in the 20–30 cm layer (b_3) was with the highest weight coefficient on the content of productive moisture in the cultivated layer (0–30 cm). The lower density in the surface layers facilitated the permeation of the rainwater down the soil profile (Heidarpur et al. 2011). In the underlying soil horizons, the capillary porosity increased with the higher density. The soil capillaries in these layers stored the moisture (Slawiñski et al. 2012) from the rainfalls after the downflow of the gravitational water. Moisture is better stored down the soil profile also due to the fact that in contrast to the surface horizons, they are not constantly subjected to the effect of the climatic factors – temperature, wind, etc., which increase the evaporation process (Romaneckas et al. 2009).

Opposite was the tendency in the regression models of the soil temperature. The bulk density in the 0–10 cm layer (b_1) was with the highest weight coefficient under the investigated soil tillage types. The lower density in this horizon conditioned the availability of more non-capillary pores, which increased the process of aeration. This layer was directly subjected to the activity of the solar radiation, accumulated thermal energy and transmitted it down the soil profile. This process was strongly influenced by the presence or absence of plant residues on the soil surface, its shadowing by plants during their vegetative growth (Dalmago et al. 2004; Fabrizzi et al. 2005; Zhang et al. 2009). After the rainfalls, under the immediate effect of the temperature and the wind, this layer dried more quickly. The early spring pre-sowing chisel plough of the soil surface also increased the soil moisture release, enriched the soil with air and accelerated its warming.

All factors – physical characteristics of the soil, climatic, biological, agronomy, had a complex effect on the temperature and the content of productive moisture in the active soil layer. This was especially important during the sowing of sunflower for the development and the productivity of the plants. The regression model gives an idea about the expected value of the specific traits – content of productive moisture and temperature of soil, according to the bulk density under the different ways of main tillage included in the model and applied in the cultivation of sunflower.

Conclusions

In cultivated soil profile of slightly leached chernozem conventional ploughing decrease the bulk density. In the layer underlying the layer where the minimal tillage was performed a slightly compaction of soil was observed. By using of tillage without turning of the soil layer, by no-tillage and minimal tillage the bulk density in the layer under the cultivated one, was changed and formed mainly under the effect of physical and climatic factors. Under all investigated types of soil tillage, the bulk density increased down the soil profile.

Replacing ploughing with tillage without turning of the soil layer, with minimal and no-tillage decreased the soil temperature. Most significant differences were observed in the 0–10 cm layer, which, on its part, created conditions for accumulation and transfer of thermal energy up and down the soil profile. The soil temperature decreased with the reduction of the number and depth of the soil tillage operations. In the areas with chisel plough, minimal tillage and no-tillage the temperature amplitudes between the surface layer and the underlying soil horizons were lower.

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